S·A·E JOURNAL

PUBLISHED BY THE SOCIETY OF AUTOMOTIVE ENGINEERS, INC.

D. G. Roos, President — David Beecroft, Treasurer

John A. C. Warner, Secretary and General Manager

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Vol. 34 — JUNE, 1934 — No. 6

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Publication Office, 56th and Chestnut Sts., Philadelphia, Pa.; Editorial and Advertising Departments at the headquarters of the Society, 29 West 39th St., New York, N. Y. Western Advertising Office, Room 2-136 General Motors Bldg., Detroit, Mich.

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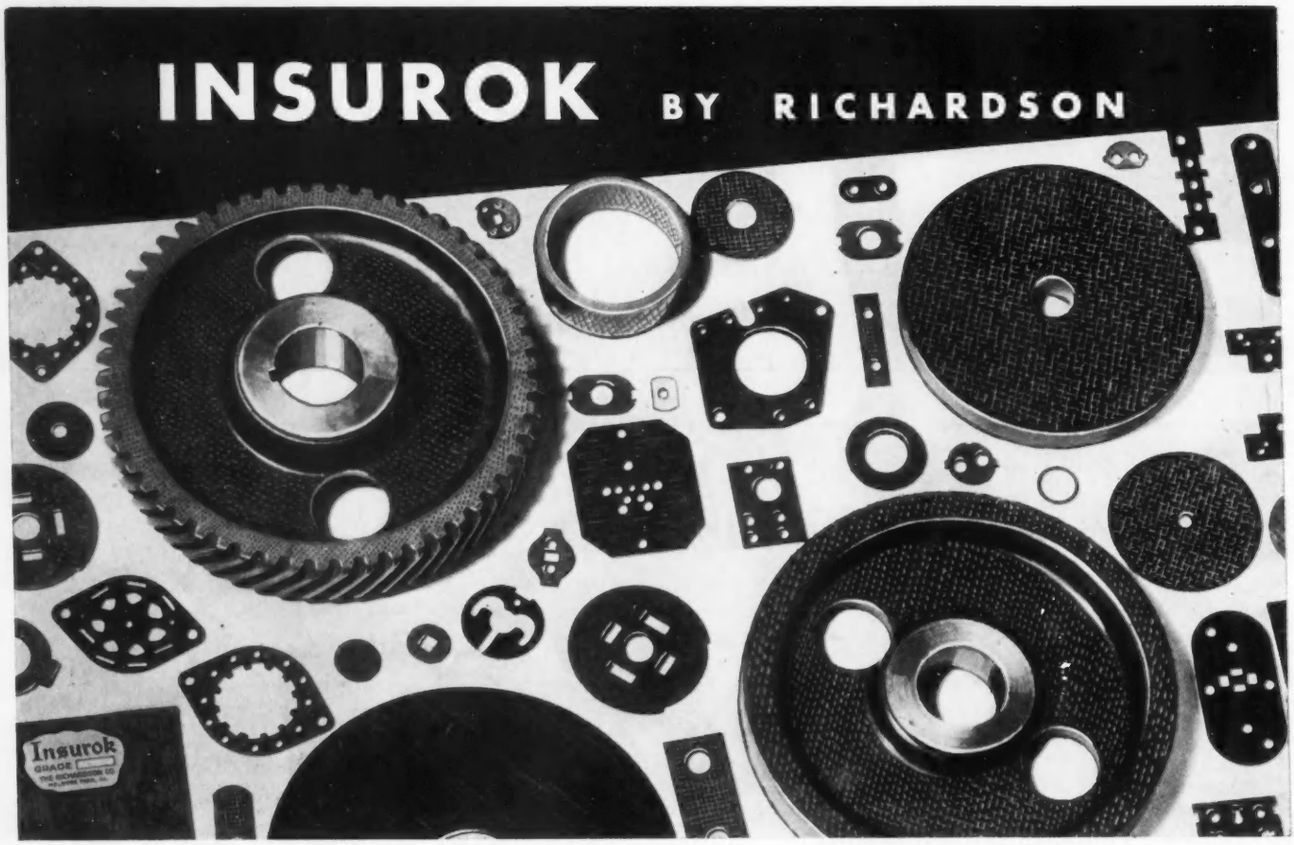
DISCOVERED

BY AUTOMOTIVE ENGINEERS !

INSUROK BY RICHARDSON



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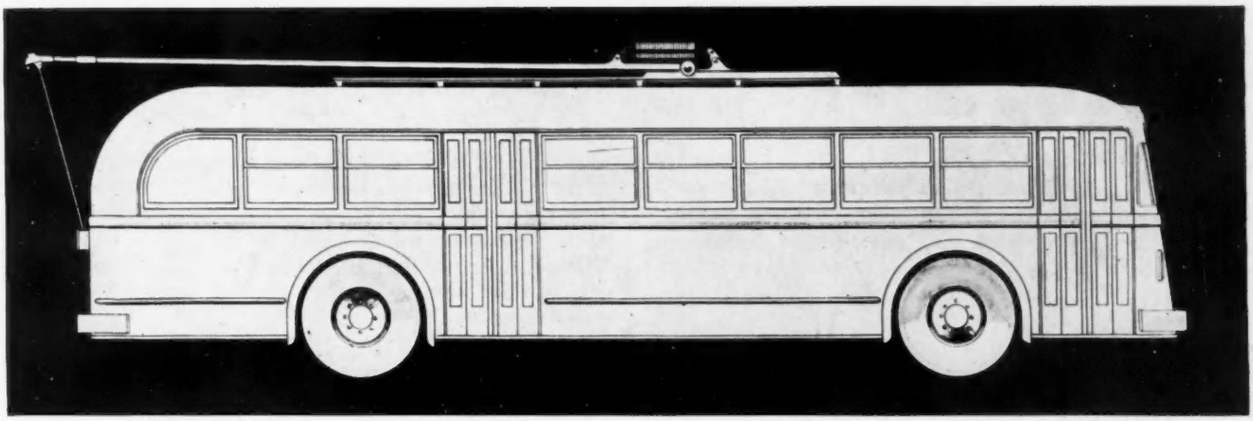
An "All-Service" Vehicle • For Passenger Transportation



By Martin Schreiber

General Manager in Charge of Plant, Public Service Coordinated Transport, Newark, N. J.

A CONVENTIONAL gasoline-electric bus can be converted for optional use as a trolley-bus, widening its functions, according to Mr. Schreiber. The "All-Service" Vehicle is equipped with a double controller, which permits shifting from trolley to gasoline-electric operation by pressing a button. Reversing the operation requires only placing the trolleys in position, so that advantage may be taken of central-station current on long grades and for other special-service conditions.

STREET-CAR operation has demonstrated the efficiency and low cost of central-station power supply in the operation of local-transportation vehicles. No other form of power has the same degree of efficiency as electricity in delivering the energy needed to perform varying quantities of work. The electric motor can take 100 per cent or more overload for short periods. We should therefore make use of electric energy whenever circumstances permit.

The trolley-bus has many advantages; it is quieter and can accelerate faster than any other highway vehicle of equal seating capacity. Moreover its operation is not limited to trolley rails even if it does require overhead wires. It can also take its proper position on the highway with private motor vehicles, including the highly important advantage under present-day traffic conditions of loading and unloading at the curb. It can be said therefore that the trolley-bus has many important advantages that should be used if practical, including speed, quietness, comfort, and elimination of fumes and disagreeable odors.

Consider the gasoline motor-bus for a moment. For real flexibility in highway transportation it has no equal, being comparable to the private automobile in this respect. This flexibility not only permits the bus to take its proper place and maneuver freely in the flow of traffic on the highway, but also allows it to run on and off to a garage by whatever route is the most desirable. It can also detour on other highways, in case of fires, burst water mains, floods, street improvements, parades, temporary route extensions and permanent extensions through parks where wires are not erected. In addition, the gasoline motor-bus is able to provide special or chartered trips to and from any point served by highways. The efficient characteristics of the motor-bus should not be overlooked.

Is it possible to unite into one vehicle at a reasonable cost all the desirable qualities of street-cars, trolley-buses and gasoline motor buses, which have just been described? The answer is yes. All that needs to be done is to take an ordinary type gas-electric bus now in general service, install a set of trolley poles on its roof and substitute a double electric controller for the present one, so that the driver of the vehicle can shift from one operation to the other at will. Although it may be necessary at times for the driver to leave his seat to place the trolley poles on the wire, as is the case with street cars and trolley-buses, when leaving the wires he can automatically remove the trolley poles by simply pressing a button actuating an electric retriever.

A new dual controller also regulates the electricity that flows from the generator to the two propulsion motors at-

[This paper was presented at a meeting of the Cleveland Section, March 12, 1934.]

Illustration above shows a proposed metropolitan type 44-passenger "All-Service" Vehicle.

tached to the gasoline engine when the vehicle is used as a gas-electric bus. In addition it controls the current supplied to the same propulsion motors when the trolley pole shoes are in contact with the overhead wires. The propulsion motors are wound for approximately 250 volts and when connected to the 500-volt trolley wires they are placed in series across them. The dual controller of the "All-Service Vehicle" may be operated either by hand or foot lever. In order to make full use of both operations at will, the lighting generator should be connected to one of the propulsion motors. If air brakes are used, in addition to the air pump connected to the gasoline engine, another air pump should be driven by the propulsion motor.

The foregoing principles were used in the experimental test of the first "All-Service Vehicle" at Weehawken, N. J., Jan. 11, 1934. The trial was made on Pershing Road, extending about one-half mile from the terminal of the West Shore Railroad & Ferry Co. to Hudson County Boulevard East. The location was selected on account of a long 6 per cent grade and the opportunity it affords to compare the performance of the new vehicle with street cars and motor buses. This route is extensively used by private automobiles, trucks, local gasoline, gas-electric and interstate motor buses. Another reason this location was selected was the fact there was a street-car line running parallel to Pershing Road, making it convenient to string a pair of 3/0 grooved wires over the road about 12 ft. from the eastern curb. These wires were supported by brackets attached to poles already in position in the retaining wall separating the road and track. The gas-electric bus which was converted into an "All-Service Vehicle" for this experiment was one of a type in regular operation on a route that included the Pershing Hill Road and the West Shore Railroad & Ferry Company's terminal.

On the day of the test the "All-Service Vehicle" was driven down Pershing Hill Road under its own power, operating as a usual gas-electric bus. Arriving at the Ferry Loop, approximately 30 persons interested in the experiment boarded the bus. In the meantime the driver shut off his gasoline engine, alighted and placed the trolley poles on the wires. When all were aboard, he notched up the controller, allowing central-station electric current to pass into the propulsion motors. As the bus proceeded up the hill it passed by most of the vehicles on the highway with ease. Upon arriving near the end of the wires at the top of the hill, the driver started the gasoline engine, shut off the electric current, the trolley poles were pulled down in position by the retrievers, and the "All-Service Vehicle," without stopping, continued on its way as a gas-electric bus again.

Tests showed that the "All-Service Vehicle" negotiated the grade at a maximum speed of 30 m.p.h. with a full load of 30 passengers. This compares with a normal maximum speed on the hill for ordinary gas-electric buses of 10 to 13 m.p.h., street cars 12 to 15 m.p.h., interstate gas-mechanical buses 15 to 18 m.p.h., and the private cars 20 to 40 m.p.h. It was determined from electrical data that if a gas-mechanical bus were to duplicate the speed of the "All-Service Vehicle," it would require an engine of 252 hp.

The "All-Service Vehicle" was equipped with a General Motors' 400-cu. in. poppet-valve engine, which develops 105 hp. at 2000 r.p.m. A General Electric No. 1121 generator, and two General Electric No. 1151 propulsion motors were used. The capacity of the "All-Service Vehicle" was 29 passengers.

Inasmuch as a gas-electric motor bus is the basis of the "All-Service Vehicle," it may be of interest to discuss this unit. One of the largest operators of motor buses in the country has been using the gas-electric bus for eight years and in this time has piled up a total of one-third of a billion gas-electric bus miles.

The gas-electric units are simply standard buses manufactured by The A.C.F. Motors Co., General Motors, Mack and White companies, with capacities ranging from 25 to 73 passengers. Generally, the clutches, transmission and differentials were omitted and electric generators and propulsion motors added. The electric installations were made by the General Electric and Westinghouse companies. The weight of the buses is generally 1400 lb. more for the 2-motor and 1100 lb. more for the single motor equipment than comparable gas-mechanical buses.

Most of the gas-electric buses are used on city and interurban lines. Some, however, have been satisfactorily used

Fig. 1—Yellow Coach, 1926, Model Z, Equipped as an "All-Service" Vehicle. Mileage 318,332.32

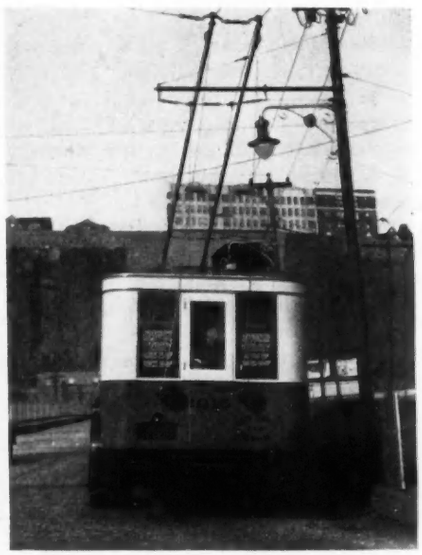


Fig. 2—"All-Service" Vehicle on Weehawken test

on high speed inter-city lines, which maintain a scheduled speed of 30 m.p.h., including stops, for 200-mile round trip runs.

This type of bus has a very great advantage from an operating standpoint. At garages, where both gas-electric and straight gasoline buses are operated, if he has a choice, the driver will invariably insist on taking a gas-electric bus. This is due to its easier driving qualities and the vehicle's popularity with the patrons who like the smooth operation. There is, of course, no shifting of gears, clutches and, outside of braking, the bus is entirely controlled by the accelerator.

For all practical purposes the gas-electric bus is the answer to the automatic clutch and transmission. It is worth all the research work and efforts of automotive engineers to do this satisfactorily in some mechanical way as they have been trying to do for the past decade. If automatic clutches are

Fig. 3—Controller for dual operation on "All-Service" Vehicle

desirable for private cars, they are more so in the driving of buses, inasmuch as the bus driver has additional duties and is responsible for a number of people.

Attention is called to the fact that it is less difficult to break in operators for gas-electric buses than the straight gasoline vehicle. It is easy to do this even if the applicant has never operated an automobile. In changing from streetcar to bus operation, especially with older men who have been reliable workers, many men are not able to learn to drive a straight gasoline bus, along with the other duties required. But with the gas-electric bus there is seldom, if ever, any difficulty encountered in making this shift.

In ordinary practice of transportation companies, it is often necessary to have several operators for a particular vehicle in the same day. Gasoline buses of the same type often seem to respond differently to different drivers in the handling of clutches and gear shifts. The tricks or kinks to learn about the gas-electric bus are limited. You have only the range of the accelerator from the normal position to the

Fig. 4—Interior View of "All-Service" Vehicle

position on the floor to consider, and this takes care of most of what the average automobile driver accomplishes by clutch and gear manipulations.

After all, bus drivers are only human beings; they get tired, annoyed and disgruntled like most of us. What the bus driver can do to a load of passengers by improper manipulation of clutch and gear shifts, not saying anything about the damage to the equipment, to put it mildly, is quite sufficient. In this era of modern business no enterprise is likely to succeed which does not give consideration to its employes as well as the comfort and convenience of the public.

The absence of disagreeable fumes in gas-electric buses is notable. The public is very apprehensive of any odors caused by gasoline engines. Immediately there is fear that poisonous monoxide gases are present, although carbon monoxide gas cannot be detected by the senses. It is unfortunate, therefore, that most large bus engines often emit odors of raw gas. This frequently occurs when the driver decelerates his engine by shutting off the gasoline supply as the engine is being turned over by the inertia of the vehicle and more gas is being sucked into the carburetor than is necessary at the moment. This condition never occurs in a gas-electric bus because there is no mechanical connection between the engine and driving mechanism.

When the highways are covered with ice and the going is slippery, gas-electric buses apply power to each rear wheel which is an advantage over gasoline buses equipped with differentials. Also, by the use of the electric brake, the gas-electric bus affords safer operation when descending icy grades. During the recent stormy weather, one transport company, operating mechanical buses, had many interruptions at loading points due to wheels spinning on ice in the streets, making it necessary to start buses with emergency trucks. Gas-electric buses, operated under similar conditions in the same neighborhood, had few, if any, interruptions due to the fact that the gas-electric bus has independent drive evenly distributed to each wheel.

One of the good points about the gas-electric bus is its ability to give an efficient account of itself as to upkeep, which includes depreciation, as well as every-day repairs. Upkeep, however, is not what it appears to be the first year of operation. There are two garages in one of our metropolitan districts which operate in city service gas-electric buses of dif-

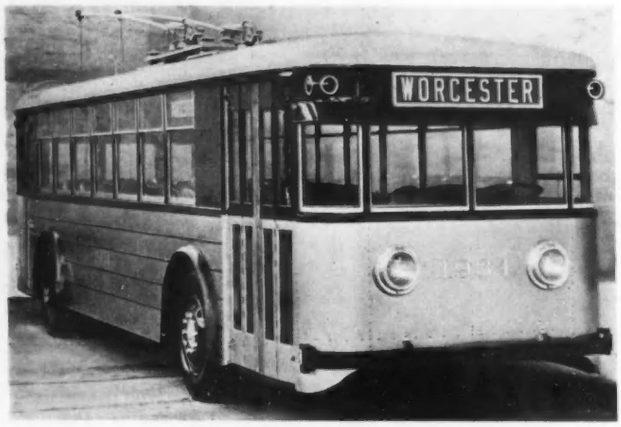


Fig. 5—Trolley-Bus, Worcester

ferent manufacture. All of these buses are approximately eight years old and have been in continuous operation during this entire time. The bus bodies and chassis at both garages are now being maintained, exclusive of depreciation, for less than 2 cents per mile.

The real truth of the matter is that there isn't anything about a gas-electric chassis, except the powerplant, that is much of a problem to maintain. The powerplant which is not mechanically connected to the driving mechanism is now in the process of being made practically foolproof by the automotive engineer, just as the electrical engineer has done with electrical equipment. The chassis may be easily separated into distinct units. The powerplant consists of the gasoline engine and electric generator, and in case of two-motor drives, duplicate propulsion units made up of motor, drive shaft, worm and gear. The driving mechanism is the essence of reliability, due not only to smoother application of power from the motors, but also on account of having just one-half the load that is required in a single drive like a gas-mechanical bus with a differential. Likewise, the twin driving mechanisms are entirely separated from one another as well as the other chassis units. This independent set-up of the chassis units gives a very great advantage in important overhauls and makes it comparatively easy to bring the operation of the vehicle back like new as to performance and quietness. While with the gas-mechanical bus the units are all tied together and it is difficult to bring the vehicle back to newness without going over the entire job and taking it out of service for long periods and at additional cost. Due to the feature of the gas-electric job that a powerplant can be easily substituted without disturbing the rest of the chassis, this is being done. When Diesel engines are sufficiently developed it will be very simple to substitute them in any of the gas-electric buses that are now in operation.

Fig. 6—Double-Deck Trolley-Bus, London

The things that have militated against wider use of the gas-electric bus in the past are engine performance, weight and fuel. In the early days of bus operation, when gasoline engines of sufficient horsepower were not developed as yet to adequately take care of the service demands, it was, of course, difficult to use the gas-electric principle where energy must necessarily be lost in the change of form. Along with the additional weights of gas-electric unit above that of the mechanical parts replaced and insufficient power, these first gas-electric jobs showed up poorly. Of course, these conditions had been largely rectified by automotive engineers who have since introduced higher speeds, compression and improved bearings with more positive lubrication.

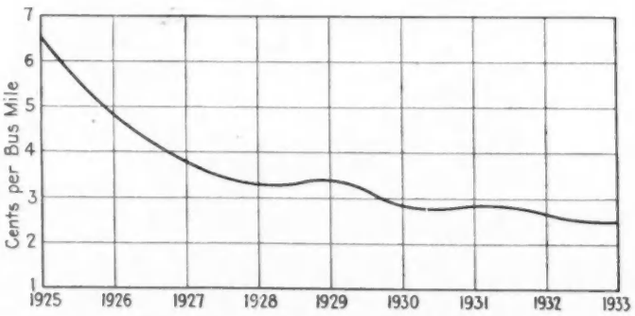


Fig. 7—Cost of Body and Chassis Maintenance (Standard Classification). Mixed Fleet of 2400 Buses Operated One-Half Billion Miles

Since 1925 to date the weight per horsepower for electric drive was reduced about 40 per cent.

Just recently on one property a number of old 468 cu. in. engines were removed from gas-electric jobs and new 400 cu. in. engines substituted. These latter jobs showed, with less weight, a 30 per cent improvement in performance, for the same fuel consumption and used considerably less oil for lubrication.

Speaking generally of weight in public transportation vehicles, desirable as it is to eliminate it, one must remember that it requires a reasonable amount of weight to transport human beings safely at reasonable speeds. The chief engineer of one of the largest steam roads in the world recently remarked: "Imagine what would happen if several hundred people were in a train and it jumped the track or had a head-on collision at 100 m.p.h., if the train were constructed after some of the 'tin-can' designs that are now being proposed for the railroads." At many scrap yards there is interesting evidence how a few years ago the street railways were going to be saved by the use of lightweight single truck cars. The foregoing does not gainsay that weight should not be removed where science and operating experience justify it with reasonable safety.

After all, the real question is what about the operating characteristics and the fuel consumption of the gas-electric bus. It has been learned by experience of millions of miles of operation that the acceleration, when taken together with the

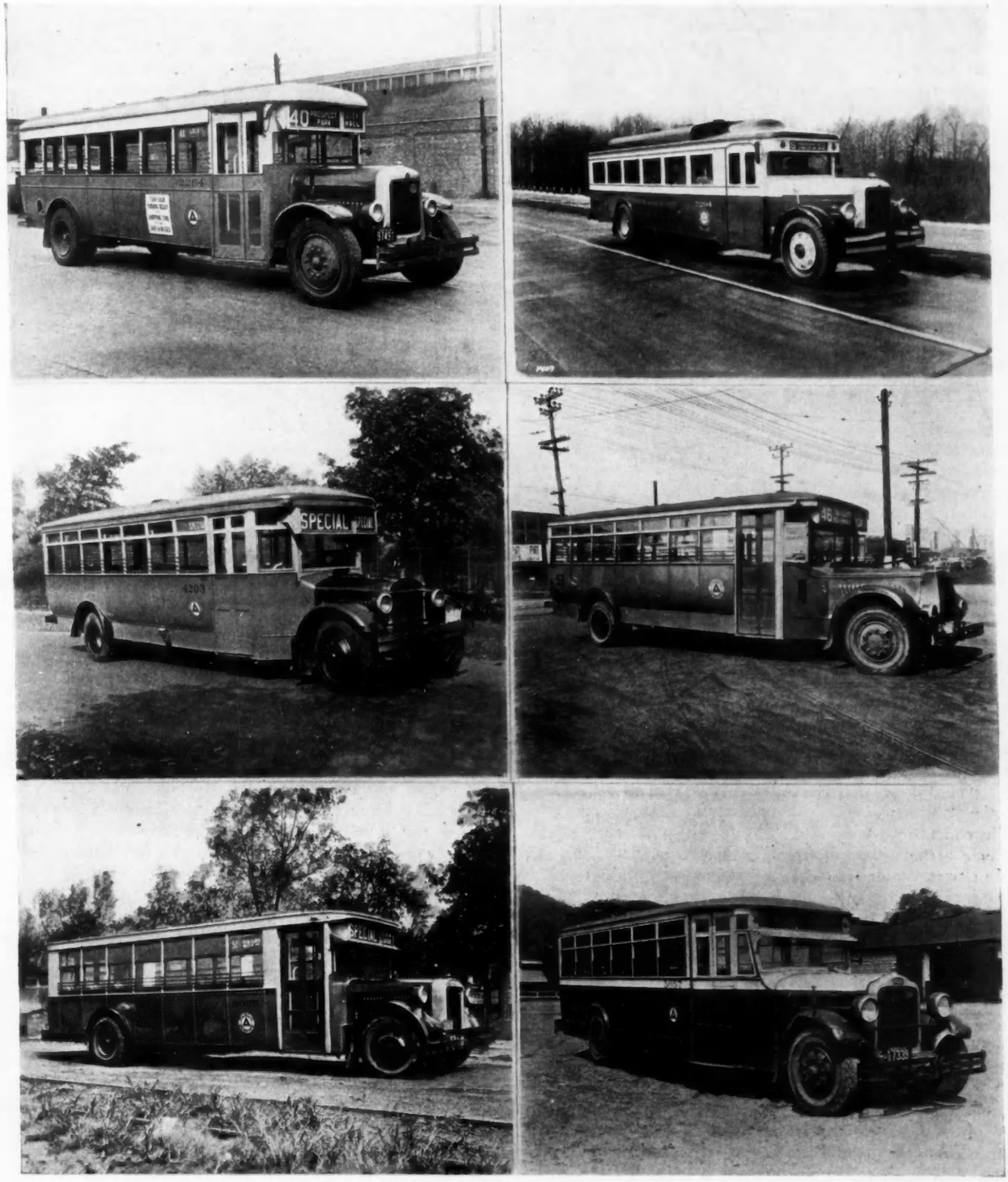


Fig. 8—Types of a Fleet of 1400 Gas-Electric Buses Which Have Operated One-Third of a Billion Miles

The gas-electric units are simply standard buses manufactured by The A. C. F. Motors Co., General Motors, Mack and White companies, with the capacities ranging from 25 to 73 passengers. Generally, the clutches, transmission and differentials were omitted and electric generators and propulsion motors added. The electric installations were made by the General Electric and Westinghouse companies. The weight of the buses are generally 1400 lb. more for the two-motor and 1100 lb. more for the single-motor equipment than comparable gas-mechanical buses.

other duties imposed on the driver, such as opening and closing doors, making change, and looking after the comfort and safety of the passengers, that the gas-electric bus is actually faster than the gas-mechanical, which makes for faster scheduled speeds. This is on account of the time lost in shifting gears and clutch when starting and stopping. These advantages obtain where there are a large number of stops per mile, although the gas-mechanical bus is somewhat more efficient in hill climbing. Also, fuel cost is 15 per cent more to operate a gas-electric than a straight gasoline bus.

Additional Fuel Cost Offset

This additional cost of fuel consumption requires only 4 per cent faster schedule to offset it. Four per cent faster scheduled speed would not be unusual for the gas-electric bus to make over the gas-mechanical bus. So, without any additional cost, the gas-electric bus gives a more comfortable and smoother ride, less inconvenience from gas fumes and interruptions, easier work and less fatigue for the driver, with less or no more maintenance cost in the long run.

Let us return to the "All-Service Vehicle." The equipment that was used in the Weehawken experiment was made with a gas-electric bus eight years old which has operated more than 300,000 miles. If the principles that have been expounded hold under these conditions, we should be able to prove them in a better way, if full advantage would be taken of modern design.

In building a new "All-Service Vehicle" the general design could follow the metropolitan streamline metal body, say, 33 ft. long, 96 in. wide, with a capacity of 44 passengers. The engine and generator could be placed anywhere. It could be conveniently taken in or out, or later substituted with a Diesel powerplant if found more economical. Or the engine and generator could be removed entirely for a period of time if the operating conditions would justify such a procedure. The two propulsion motors could be located to connect with the rear axle so that the job would be properly balanced and designed to take current for operation from either its own powerplant or trolley wires. In addition, the bus would have the necessary trolley poles easily removed if the vehicle was going to operate for long periods as an independent gas-electric bus. With this particular type of vehicle perhaps the proper engine would be one of 125 hp. The electric motors would be wound not only to take care of their normal capacities, but in addition, an overload of 100 per cent for short periods so as to gain quick acceleration. The weight of vehicle light should not exceed 17,000 lb.

In conclusion we might summarize the advantages of the "All-Service Vehicle" as compared with other types of vehicles used in modern transportation as follows:—

Contrasting it with the conventional gasoline motor bus it will be found considerably more efficient for the same performance, inasmuch as the electric motors may be wound to take care of overloads without interfering with the efficiency of the average operation. If you have a gasoline motor large enough to obtain satisfactory speed on hills, it will be larger than necessary for a level run and therefore more or less inefficient. Additional advantage over the gasoline bus is the fact that the "All-Service Vehicle" may be used in surface, subways or tunnels without the installation of expensive ventilating systems that are necessary to eliminate gasoline fumes. Automotive engineers have been working for years to obtain automatic transmissions and clutches, so that the rider may get the most comfortable service and so the operation of the car may be as easy as possible.

The gas-electric features of the "All-Service Vehicle" not only eliminate the clutch and transmission but also the differential, where there are two electric motors, so that on the whole it affords a smoother and quieter ride.

The electric drive does not limit the position of the powerplant as in the straight gasoline motor bus where the engine is physically connected with drive shafts and gears. With the electric drive the gasoline engine may even be placed crosswise in the rear and under the body of the bus where it would be readily accessible for repairs. Such an arrangement also lends itself to any replacement by improved powerplants.

Likening the "All-Service Vehicle" with the trolley-bus—in this role it can furnish the same service as the trolley-bus, but in addition it has the superiority of flexibility. Besides, a route may be extended; detoured; overhead trolley and wire construction at garages and terminals is not necessary; the shortest distances for run-ons and run-offs on lines may be selected and special business to and from any place may be carried on. If there are sections similar to a park or boulevard, where transportation is required with the "All-Service Vehicle," it may be accomplished without the use of any wires or additional construction of any kind.

Comparing the "All-Service Vehicle" to the street car, it will do almost everything that the street car will do, even carry maximum loads by double decking and a great deal more. It will also exceed the conventional street car in acceleration, smoothness of operation, and quietness. Furthermore, it will perform the important functions for the riders that are almost hopeless for the street car, and that is curb loading and unloading of passengers. Nor does it require rigid rails, special rail work, or overhead wires and poles, but uses instead the common highway for extensions, detours, or special business or to go anywhere the private automobile is taken.

Substitution of Buses Studied

At the meeting of the National Association of Motor Bus Operators during the Century of Progress at Chicago, the Special Consulting and Development Committee reported:

"One of the difficult problems facing us is how certain street car lines may be substituted with motor buses and at the same time preserve at least part of the street car property. An answer to this question is to use the well-known trolley-bus. One of the world's transportation authorities, Lord Ashfield, speaking on London Passenger Transport before the Royal Institute of Great Britain, in March, last, said: 'The solution of the tramway problem appears to be in the direction of trackless trolley vehicle of equal capacity to that of the tramcar, free from the rigidity imposed upon it by the necessity of running on rails.' However, in making substitutions in this country, especially in the smaller cities, it is often desirous to change some of the original routes or to make certain detours or extensions to the street car lines.

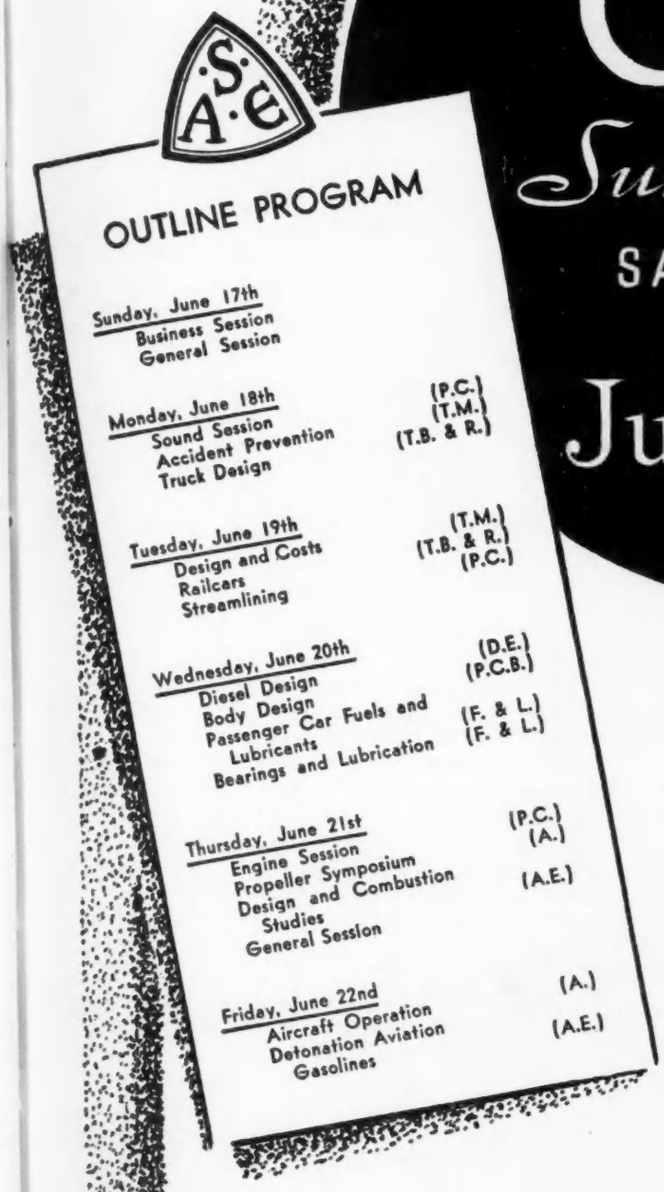
"A suggestion worthy of consideration in this dilemma is the use of the well-known gas-electric bus as now developed, having a gas engine and an electric generator and two propulsion motors. By the addition of trolley poles and control mechanism to the gas-electric bus, you have a vehicle that may be used either as a trolley-bus when the engine and generator are cut out, or as a motor bus by the simple operation of pulling down the trolley poles. Here, then, would be a vehicle that would meet the requirements of the trolley-bus or the ordinary city motor bus, and at the same time the generating and distribution portions of the plant of the street railway would be preserved."

Last Call

Summer Meeting

SARANAC INN
NEW YORK

June 17–22



OUTLINE PROGRAM

Sunday, June 17th
Business Session
General Session

Monday, June 18th
Sound Session (P.C.)
Accident Prevention (T.M.)
Truck Design (T.B. & R.)

Tuesday, June 19th
Design and Costs (T.M.)
Railcars (T.B. & R.)
Streamlining (P.C.)

Wednesday, June 20th
Diesel Design (D.E.)
Body Design (P.C.B.)
Passenger Car Fuels and Lubricants (F. & L.)
Bearings and Lubrication (F. & L.)

Thursday, June 21st
Engine Session (P.C.)
Propeller Symposium (A.)
Design and Combustion Studies (A.E.)
General Session

Friday, June 22nd
Aircraft Operation (A.)
Detonation Aviation Gasolines (A.E.)

LAST call for the S.A.E. Summer Meeting at Saranac Inn.

Six days filled with intensely interesting technical sessions—read the program on the two following pages and find the sessions that you will want to attend. This year's Summer Meeting offers every member a big S.A.E. dividend at a new low in investment cost.

Delightful surroundings in the heart of the Adirondacks on Upper Saranac Lake afford a pleasant setting for the many technical discussions and committee meetings, with an occasional chance for recreation and ample opportunity to renew acquaintances in the industry. The back page tells you the names of the "Early Birds" who have already sent in their reservations.

LAST CALL!—SEND IN YOUR RESERVATION AT ONCE

SUNDAY, JUNE 17

8:15 P.M. — **Business Session**

President D. G. ROOS in the Chair

8:30 P.M. — **General Session**

ALEX TAUB, Chairman

Revelations in the Realm of Color—H. T. STRONG, William Wiese & Co.

MONDAY, JUNE 18

10:00 A.M. — **Sound Session**

W. C. KEYS, Chairman

The Place of Sound Measurements in Automobile Noise Reduction—DR. E. J. ABBOTT, University of Michigan

10:00 A.M. — **Accident Prevention Session**

F. K. GLYNN, Chairman

Accident Control in Fleet Operation—J. M. ORR, Equitable Auto Co.

2:00 P.M. — **Water Carnival**

8:30 P.M. — **Truck Design**

A. G. HERRESHOFF, Chairman

Lightness in Motor Trucks—A. M. WOLF, Consulting Engineer, New York, N. Y.

TUESDAY, JUNE 19

10:00 A.M. — **Motor Vehicle Design**

L. V. NEWTON, Chairman

Vehicle Design from a Maintenance and Operating Standpoint—F. L. FAULKNER, Armour & Co.

Weight Distribution on Front and Rear Axles of Motor Trucks—E. L. TIRRELL, Utility Management Corp.

10:00 A.M. — **Railcars**

L. R. BUCKENDALE, Chairman

Trends in the Design and Application of Motor Trains—C. O. GUERNSEY, J. G. Brill Co.

2:00 P.M. — **Field Day**

8:30 P.M. — **Streamlining Session**

W. T. FISHLEIGH, Chairman

Dynamics of Automobile Design—G. L. McCAIN, Chrysler Corp.

Streamlining—Up-to-date Facts and Developments—L. H. BROWN, Jaray Streamlining Corp. of America, and HERBERT CHASE, Consulting Engineer, New York, N. Y.

WEDNESDAY, JUNE 20

10:00 A.M. — **Diesel Design**

F. M. YOUNG, Chairman

Diesel Fuels—K. E. DE ROSAY, Sun Oil Co.

Effective Combustion as Determined from the Indicator Diagram—J. C. SLONNEGER, Falk Corp.

Typical Indicator Diagram Analysis with Respect to Effective Combustion—HANS FISCHER, Electric Boat Co.

Spark Ignition Injection Engines of High Output—TUNGBJOERN DILLSTROM, Hesselman Motor Corp., Sweden

10:00 A.M. — **Body Design**

J. W. VOTYPKA, Chairman

Basic Principles of Body Design—W. D. TEAGUE, New York, N. Y.

2:00 P.M. — **Passenger Car Fuels and Lubricants**

A. L. CLAYDEN, Chairman

Winter Oils in Automobile Engines—W. H. GRAVES, Packard Motor Car Co.; H. C. MOUGHEY, General Motors Corp., and E. W. UPHAM, Chrysler Corp.

Fuel Characteristics and Vapor Lock—O. C. BRIDGEMAN, Bureau of Standards

8:30 P.M. — **Bearings and Lubrication**

FERDINAND JEHLE, Chairman

Recent Developments in Main and Connecting Rod Bearings—S. W. SPARROW, Studebaker Corp.

Lubrication of Engines with Different Bearing Metals, with Special Reference to Copper Lead Alloys—C. M. LARSON, Sinclair Refining Co.

E. P. Lubricants—Report and Demonstration—W. S. JAMES, Studebaker Corp.

THURSDAY, JUNE 21

10:00 A.M. — **Engine Session**

K. M. WISE, Chairman

Engine Types Adapted to Automobile Design Trends—L. P. KALB, Continental Motors Corp.

The Possibilities of Forced Induction in Automotive Vehicles—LOUIS SCHWITZER, Schwitzer-Cummins Co.

PROGRAM . . .

THURSDAY, JUNE 21

(Continued)

10:00 A.M. **Propeller Symposium**

E. P. WARNER, Chairman

Controllable Pitch Propellers—F. W. CALDWELL, Hamilton Standard Propeller Co.

The Design Requirements of a Mechanical Controllable Propeller—G. T. LAMPTON, Lycoming Mfg. Co.

Controllable Pitch Propellers—Design Considerations—T. P. WRIGHT, Curtiss Aeroplane & Motor Co.

Bearings for Controllable Propellers—THOMAS BARISH Marlin-Rockwell Corp.

2:00 P.M. **Design and Combustion Studies**

ROBERT INSLEY, Chairman

Observations of Flame in an Engine—C. F. MARVIN, JR., Bureau of Standards

Design Limitations of Aircraft Engines—E. S. TAYLOR, Massachusetts Institute of Technology

8:30 P.M. **General Session**

A. L. CLAYDEN, Chairman

LOWELL THOMAS

10:00 P.M. **Grand Ball**

FRIDAY, JUNE 22

10:00 A.M. **Detonation Aviation Gasolines**

H. K. CUMMINGS, Chairman

Correlation of Knock Ratings of Aviation Gasolines—ARTHUR NUTT, Wright Aeronautical Corp.

10:00 A.M. **Shock Absorber Session**

T. P. WRIGHT, Chairman

The Airplane Landing-Gear Shock-Absorbing System—C. V. JOHNSON, Bendix Products Corp.

Be sure to see the

Transportation Revue

An exhibition of the latest forms of modern transportation including Passenger Cars, Trucks and Planes, with an opportunity for you to inspect and operate this equipment. Engineers will be there to explain and demonstrate the newest design features.

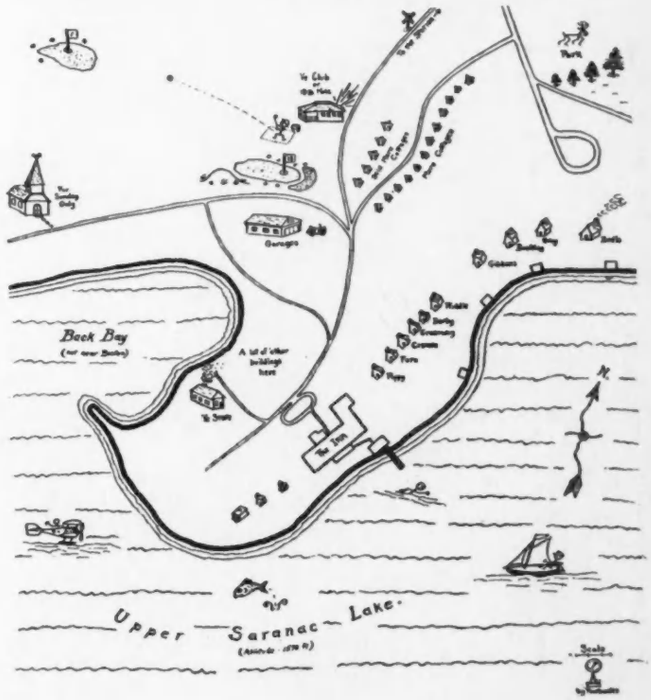
Social and Recreational Features

Golf Tournaments	Tennis	Fishing
Field Day	Bridge	Ping Pong
Water Carnival	Trap Shooting	Dancing

Enclosed with the Bulletin Mailed May 15th

Hotel Reservation Blank
Railroad Timetable and Fares
Reduced Fare Certificate
Airport Facilities and Driving Data

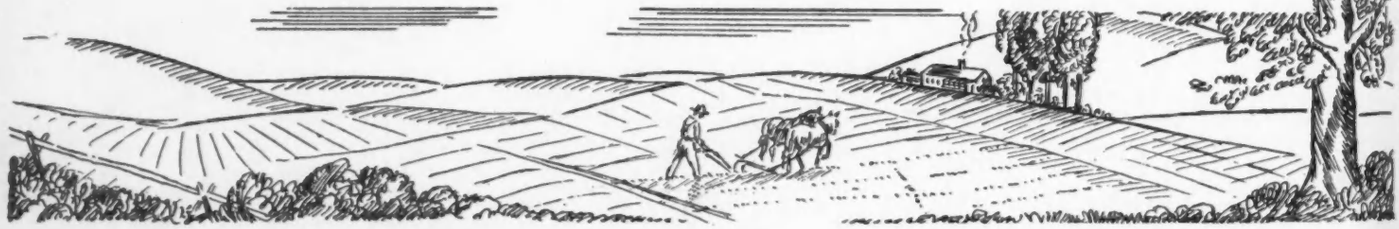
An Early Bird's Eye View of Saranac Inn



Early BIRDS

The Following Are A Few Of The People Whose Reservations Had Already Been Received Before May 10th

F. F. Alborn
H. W. Alden
E. A. Anderson
Mrs. E. A. Anderson
J. A. Anglada
Mrs. J. A. Anglada
Miss Charlotte Anglada
M. D. Archangeli
E. W. Austin
Mrs. E. W. Austin
W. Babler
B. B. Bachman
W. C. Baker
Mrs. W. C. Baker
W. A. Baker
J. R. Bartholomew
C. H. Baxley
R. S. Begg
Mrs. R. S. Begg
Miss Begg
Vincent Bendix
Donald Blanchard
H. F. Blanchard
Mrs. H. F. Blanchard
L. F. Body
Mrs. L. F. Body
L. D. Boyce
S. L. Bradley
R. P. Breese
W. S. Brink
A. E. Bronson
Mrs. A. E. Bronson
Gordon Brown
L. H. Brown
R. W. Brown
Sandford Brown
L. R. Buckendale
A. A. Bull
R. L. Busse
S. M. Cadwell
C. C. Carlton
J. L. Carson
J. F. Cast
T. B. Chace
A. C. Chambers
M. E. Chandler
Herbert Chase
Julian Chase
W. G. Clark
E. M. Clissold
A. F. Coleman
F. H. Colvin
Howard Cooper
R. H. Daisley
R. C. Darnell
W. J. Davidson
T. C. Delaval-Crow
R. H. De Mott
Mrs. R. H. De Mott
Howard Dingle
J. L. Dole
C. E. Dwyer
Graham Edgar
Wm. Fairhurst
Mrs. Wm. Fairhurst
R. N. Falge
Mrs. R. N. Falge
W. H. Farr
M. P. Ferguson
H. E. Figgie
Mrs. H. E. Figgie
Miss Figgie
Master Figgie
R. A. Firestone
L. W. Fischer
L. W. Fox
D. L. Gallup
F. K. Glynn
Mrs. F. K. Glynn
R. J. Goldie
H. A. Gossner
J. T. Greenlee
Mrs. J. T. Greenlee
W. B. Groves
J. C. Halbleib
Mrs. J. C. Halbleib
J. E. Hale
H. Hammi
Mark Harris
Mrs. Mark Harris
C. H. Havill
P. M. Heldt
E. J. Hergenroether
R. R. Hirsch
G. W. Hobbs
Mrs. G. W. Hobbs
M. C. Horine
H. F. Huf
Mrs. H. F. Huf
J. H. Hunt
H. K. Intemann
Frank Jardine
Mrs. Frank Jardine
Robert Jardine
Mrs. Robert Jardine
Ferdinand Jehle
W. F. Jennings
H. G. Johnson
R. W. Keeley
Moore Kelly
Mrs. Moore Kelly
A. R. Kepler
Mrs. A. R. Kepler
V. W. Kliesrath
C. F. Kreuger
G. M. Kryder
A. A. Lane
Mrs. A. A. Lane
R. P. Lansing
S. F. Lentz
W. L. LePage
L. E. Lighton
Mrs. L. E. Lighton
C. R. Mabley
Neil MacCoull
Mrs. Neil MacCoull
W. L. McGrath
Charles Marcus
E. S. Marks
Mrs. E. S. Marks
G. T. Moore
W. T. Murden
C. A. Musselman
R. J. Nightingale
J. M. Orr
F. W. Parker, Jr.
A. J. Poole
M. L. Pulcher
C. P. Rector
R. M. Riblet
W. F. Rockwell
Mrs. W. F. Rockwell
D. G. Roos
Miss Roos
G. S. Salzman
Mrs. G. S. Salzman
Curt Saurer
A. J. Scaife
H. A. Schatz
Mrs. H. A. Schatz
Miss Helen Schatz
C. H. Schlesman
E. M. Schultheis
Mrs. E. M. Schultheis
Louis Schwitzer
Mrs. Louis Schwitzer
Louis Schwitzer, Jr.
H. L. Sharlock
F. A. Sharpe
Z. Soucek
S. W. Sparrow
J. W. Spray
Mrs. J. W. Spray
W. B. Stout
Alex Taub
Mrs. Alex Taub
H. M. Taylor
R. R. Teetor
Mrs. R. R. Teetor
R. H. Trese
J. C. Tuttle
Mrs. J. C. Tuttle
A. S. Van Halteren
G. W. Waters
Mrs. G. W. Waters
G. D. Welty
M. P. Whitney
T. H. Wickenden
Mrs. T. H. Wickenden
F. B. Willis
H. E. Winkler
Mrs. H. E. Winkler
A. M. Wolf
Ernest Wooler
Mrs. Ernest Wooler
V. C. Worden



Chronicle *and* Comment

By
Norman G. Shidle

GENERAL revision of S.A.E. steel specifications, now being made, marks complete modernization of one of the most valuable set of standards ever developed by the Society. Despite continued acceleration in the use of S.A.E. steel specifications in a variety of industries as well as in the automotive field itself, development of new alloys and changes in others have made general survey of the whole group desirable.

Important in the contemplated revision will be the addition of specifications on carbon series with higher manganese content, on nickel-chromium steels, and on nickel-chrome-molybdenum alloys. Special attention also is being given to some of the cast-iron specifications, particularly those relating to cast iron generally used in cylinder block constructions and electric furnace iron.

Officially started at a long session of the Iron and Steel Division of the Standards Committee in Detroit near the end of April, completion of the revisions is expected to require at least six to eight months of consistent effort. Members interested will be able to follow the progress of this important activity through the "With the Committees" pages of the JOURNAL from time to time.

DELEGATION to President Roosevelt of wide powers in connection with tariffs, establishment of a government-sponsored Export-Bank and improvement in business conditions in many foreign countries combine to support the hope that current increases in automotive foreign trade will continue and be further extended.

From an engineering standpoint American automobiles and trucks have long had preference among buyers in most foreign countries. Changes in trade barrier conditions should make it easier for those buyers to express that preference in purchases.

Foreign manufacturing countries are active as well, however, in movements looking to betterment of their export possibilities. Reduction of the horsepower tax in Great Britain will tend to permit British makers to build cars for domestic consumption which will be better fitted for export sale. Integration of important Japanese automotive manufacturing companies into a single large unit gives evidence of Nipponese hopes for a share in the world automobile markets. Reorganization of Citroen in France raises French hopes of renewed participation in export increases.

World trade seems bound to continue an important element in the automobile business—and American engineering genius gives evidence of providing the basis for continuance of American leadership.

Last Minute News of Summer Meeting

PLENTY of time for discussion! That is what everybody hopes for at S.A.E. meetings. The chance of getting it at the Saranac meeting is bright. A greater number of one and two-paper sessions than ever before appear on the program.

* * *

There will be four flights in the golf tournament which will consist of 36 holes of medal play. Prizes will be given for the winner and runner-up in each flight.

* * *

Early returns indicate that Tungbjoern Dillstrom of Sweden will travel further from home to attend the Saranac meeting than will anyone else. He is scheduled to talk on spark ignition injection engines of high output.

* * *

Lowell Thomas, radio reporter, through the courtesy of the Sun Oil Co. will make an informal, non-broadcast talk to the Thursday evening session about his thrilling adventure experiences.

* * *

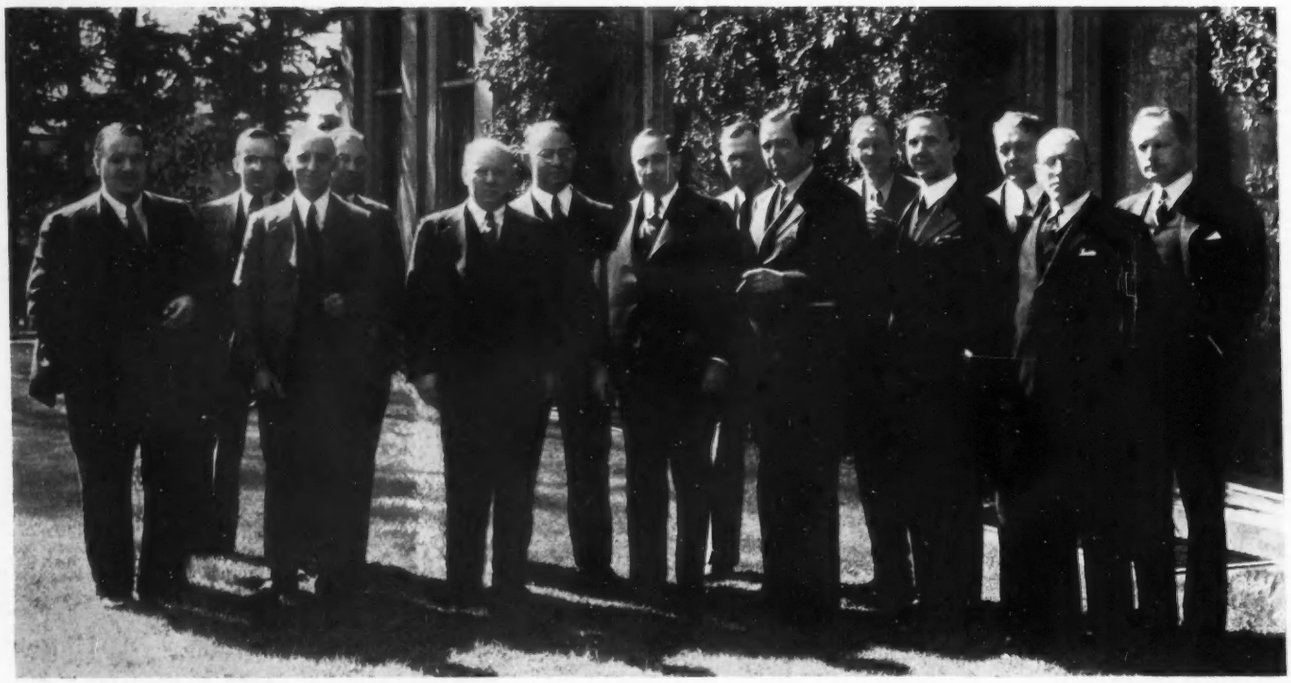
If you haven't yet made your reservations, write or wire immediately to S.A.E. headquarters office, 29 West 39th St., New York.

TWENTY Years Ago This Month: Under the heading "Good Advice," Joseph Anglada wrote a letter urging fellow members to attend the Cape May summer meeting and saying many things that still are good advice. One of them: "It is likely that you will make friends at the meeting who will be of a very direct and substantial value. . . ."

A. P. Brush read a paper on "The Ideal Automobile" and started by saying, "There is not, and never can be, an ideal automobile, but what there can and should be, is more progress toward the ideal in the motor car industry." He ended by expressing "a profound conviction that there is room throughout the whole automobile to make a more scientific use and distribution of the materials commercially available, with a resultant decrease in weight and cost and a resultant increase in initial and ultimate performance, without any sacrifice, and probably some advance, in appearance and comfort."

Participants in discussion of the Brush paper included Austin M. Wolf, Herbert Chase, N. B. Pope, J. E. Schipper, J. A. Anglada, O. A. Parker, H. G. McComb, and many others.

Quick Glimpses of S.A.E. Achievement



The Council, governing body of the S A.E., at its last meeting was entertained by Past-President Vincent Bendix at Chateau Bendix, South Bend, Ind. Back row: *(left to right)* C. B. Whittelsey, Jr., assistant secretary; J. M. Crawford, A. K. Brumbaugh, Robert Insley, A. Ludlow Clayden, J. B. Fisher, and Leonard V. Newton. Front row: John A. C. Warner, secretary and general manager; Past-President H. C. Dickinson, Past-President A. J. Scaife, Past-President Vincent Bendix, President D. G. Roos, Walter T. Fishleigh, and F. F. Kishline.

By John A. C. Warner

Secretary and General Manager,
Society of Automotive Engineers

THE tangible elements of S.A.E. functioning are well understood by almost every member, whether he lives in New York, Michigan or California; whether or not he attends Section and General meetings; and whether his interests are highly technical or lie chiefly in observation of general automotive-engineering trends.

The JOURNAL, the HANDBOOK, the Section meetings, the Annual and Summer Meetings, the special aeronautic, transportation, marine and production meetings, the Placement Service, and other similar items are easy to see and to appreciate. These are concrete things which can be listed and evaluated in dollars and cents of cost to show that in 1933, for example, an S.A.E. member got about $48 worth of service for the $20 which he paid in dues.

Important as these concrete services are, however, it has seemed that perhaps the most vital and interesting work of the Society is that embraced in the vast scope of committee activity through which the standards, the research and many other phases of Society effort function. Here in the committees, Society membership blossoms into new meaning; brings new value to those who participate; and results in practical achievements of inestimable worth.

Because the great significance of the work that goes on there is not always fully appreciated, we thought it might be interesting to take a brief tour of that land which lies behind the scenes with the committees. It is such a big country that we couldn't cover it all in a limited time, but by using the short cut of Specific Example Road we can quickly get a good idea of the sort of things that are happening.

While I am the ostensible conductor of this informal tour, other members of the headquarters staff have contributed directly and importantly to the exposition and description of vital points all along the route. Particular appreciation for cooperation in development of this material is due to R. S. Burnett, E. F. Lowe, Norman G. Shidle, C. B. Veal, and C. B. Whittelsey, Jr.

The Council, the governing body of the Society, is, of course, the most important single "committee" of all. It is

[This paper was read in May, 1934, at meetings of the following Sections: Denver, Southern California, Northern California, Northwest, and Oregon.]

charged with final decision on questions involving both technical and administrative matters, as well as with active direction of policies along positive lines. The agendas for its meetings cover a variety of subjects matched only by the diversified background of its members.

In every Section, the various committees supplement the efforts of the important general administrative and functional committees which serve the Society as a whole.

Men Make Committees

Laboring as integral parts of subcommittees with long names and commercially competitive memberships, scores of individuals have wrought finely in the common interest. Petty jealousies are largely eliminated; competitive desires fade to the background.

The continuous service of many prominent men is merely symbolic of similar effectiveness in the work by hundreds of others whose national prominence, perhaps, lies in the future rather than in the present.

In no other way perhaps is the virility of the Society of Automotive Engineers better exemplified than in the fact that nearly one-third of its entire dues-paying membership today is engaged in active, useful committee business of one kind or another.

Standardization Changes with the Times

The basic value of the standardization achievements of the Society has been long recognized and frequently applauded, but not every one realizes how definitely S.A.E. standardization policies and programs have been changed to fit the radically changed needs and conditions of recent years.

Earlier standards related almost entirely to automobile parts and fittings such as screws, bolts, nuts, rod ends, carburetor flanges, spark plugs, magneto mountings, tire sizes, ball bearings, fuel and oil line fittings, and to materials such as iron and steel, non-ferrous metals, lubricating oils and the like.

Early steel and non-ferrous metal specifications set up by S.A.E. committees were largely responsible for the development and general use of what were then the new alloy steels.

The value of these steels to all industries has been incalculable. Most of them are carried in stock in bar form by even small steel dealers and are commonly used by a great variety of industries. Typical uses are in oil well tools and power equipment, anchor chain, hoisting machinery, hydraulic presses, pumping machinery, blast furnace parts, steam and Diesel electric locomotives, rock drills, machine tools, conveyors, submarines, pneumatic tools, power snow scrapers, coin presses, sugar and paper mill machinery and parachute fittings.

During the past few weeks, the Iron and Steel Division of the Standards Committee has held two meetings which mark the beginning of a general revision of the S.A.E. iron and steel standards. Completion of the work will take six to eight months, but at the end there will have been added new specifications in the carbon series with higher manganese content, in nickel-chromium steels and in nickel-chrome-molybdenum alloys; also there will have been modernization of data on heat treating, hardness testing, normal physical properties and on the effects of mass on physicals.

This is an undertaking of great importance. Twenty years ago it was necessary to call a convention of the Society to go through with a similar purpose. Today, the work can be done through more concentrated channels. We have progressed in method as well as in accomplishment.

In the April issue of the JOURNAL is an article by Virgil M. Graham, which describes the progress made in automobile radio problems by cooperation between the Society and the Radio Manufacturers Association. It is worth reading, not only as it throws light on the particular question, but as an up-to-date example of what is accomplished by cooperative effort in standardization work and research.

Present vs. Past

The present-day automotive designer, with the S.A.E. HANDBOOK at his fingertips, can scarcely visualize the difficulties faced by earlier designers in the years before the standards were set up. Now—the engineer who designs a crankshaft, for example, can take care of the metallurgical requirements of the design merely by writing on the blueprint the proper S.A.E. specification numbers. A few minutes of "research" in the HANDBOOK will supply the information including manufacturers who will make the steel and the shaft to meet the requirements on the S.A.E. Standards.

Look back 20 years. The intrepid engineer who set out to get a satisfactory crankshaft had to go into conference with metallurgists, work out in detail a specification which seemed to meet the needs of the problem, and get a lot of samples so that an intricate series of tests could be made to determine whether the design was satisfactory. The present steel standards have saved time and money for engineers, and they are being revised constantly to meet changing conditions.

Standardization Saves Millions

A prominent official of one of our greatest companies recently spoke of the work of the S.A.E. in standardization and research as having "saved the manufacturers, and the public alike, millions of dollars." He went on to say: "It has guaranteed the integrity of our purchases. It has set up standards and bench marks of great value to the engineer who was formerly at the mercy of secret brands and unknown chemical and physical characteristics. It is a cooperative undertaking of which we all may be proud."

New conditions, brought about by mass production, lessened the need for new detail standards for the interchangeability of parts and emphasized as the standards of greatest value those of a more fundamental character which apply commonly to all industries rather than to one specialized industry.

Standardization on a national basis, in which the Society is cooperating fully, is being carried forward under the procedure of the American Standards Association and with the cooperation of Governmental agencies. Of the several hundred projects moving forward under the American Standards Association, your Society is taking an active part in all of those that have any important relation to the automotive and directly associated industries, the Society being a direct sponsor for many of the more important of these projects. Automotive interests are protected by the fact that all of these projects, prior to final adoption, must be acted upon and approved by the Society before becoming American Standards. The S.A.E. maintains its own individual standardization activities, however, for all projects that relate only or primarily to the automotive industries.

The Society has for many years maintained international contacts both directly and through the American Standards Association, with many international projects and has been instrumental in consummating international agreements. Possibly the outstanding examples of the Society's work in the international field are the unification of ball-bearing standards and, more lately, participation in the international unification of tire and rim standards in cooperation with the Tire and Rim Association.

During 1916 and 1917 the American Society of Aeronautic Engineers, the Society of Tractor Engineers, the National Association of Engine and Boat Manufacturers and the National Gas Engine Association merged their engineering and standardization activities with those of the S.A.E., and in 1917 the name of the Society was changed from the Society of Automobile Engineers to the Society of Automotive Engineers, Inc.

Not many years later, interest in the S.A.E. work sprang up among men in the manufacturing and production departments and among the motor-vehicle fleet operators. These new interests soon started to develop standards peculiar to their respective fields, those in production relating primarily to various types of small tools such as milling cutters, drills, reamers, and the like; also to features of machine tool construction such as tapers and spindle noses.

The S.A.E. Handbook of Standards and Recommended Practices has been used to an ever increasing extent by many companies in fields other than the automotive, and the number of S.A.E. Standards that have been adopted almost bodily in many of the countries abroad is encouraging and surprising.

In supplementary operations under the NRA code of the Iron and Steel Industry, S.A.E. steel specifications are used as an element in certain of the pricing provisions.

In the field of motor-vehicle operation one of the first standards developed was for a uniform system for classifying operating costs so that direct comparative studies could be made of the operation of one fleet with another. This standardized classification was also widely used as a basis for the accounting system used by fleet operators. The latest development in this connection has been the working out of three basic plans of cost recording with the necessary record forms —one for the small fleet operator, one for the medium-sized fleet operator, and one for the large fleet operator. Results of this work will be very far-reaching and of great value to the entire-fleet-operating industry, since it is being used in connection with setting up a standard method of determining costs as required by the NRA Trucking Code that became effective in February, 1934.

Research Studies Bring Practical Results

Organized in 1921 and growing largely out of a research division of the Standards Committee which functioned from 1914 to 1917, the Research Committee and its numerous subcommittees have also produced a wealth of interesting and valuable results.

For instance, few more dramatic stories exist of public service resulting from technical effort than that of the cooperative fuel research in which S.A.E. members have played so dynamic a part. In conjunction with technicians of the petroleum industry, automotive engineers, working as part of S.A.E.—A.P.I.—N.A.C.C.—Bureau of Standards committees, have provided practical remedies for a long series of car-owner troubles since the beginning of their work 13 years ago.

Cooperative fuel research disclosed, early in its work, that, contrary to general belief, the heaviest fuel that could be burned satisfactorily was the most economical.

Then it determined the causes and conditions surrounding the phenomena of crankcase dilution which resulted from the use of these heavy fuels. Establishment of easy starting requirements for engine and fuel at any temperature followed in due course and frosty doorknobs on millions of garage doors ceased to be omens of starting trouble for car owners.

Development of standard methods of measuring "knock" was the step which preceded development by industrial laboratories of antiknock materials and fuels and make possible matching of engines and fuels for maximum efficiency in performance.

Vapor lock—which every car designer admitted to be troublesome in all cars except the one which he had designed himself—came under the critical analysis of the S.A.E. and cooperating technicians and practical remedies were suggested.

Gum and sulphur troubles in gasoline were alleviated by application of the results of studies made by the cooperative fuel research groups, while definite progress has been achieved in rating and standardization of Diesel and aviation fuels along lines similar to those pursued earlier in connection with passenger car and truck gasoline fuels.

Some slight conception of the economic value of all this work can be gained from the estimate of one authority that savings in excess of $100,000,000 a year accrued to gasoline users as a result of the work on heavy and light fuels alone.

Our sourest cynic cannot help admiring the remedies that have come from effective, though at times detonating, discussion of automotive fuel problems.

The research activity has, of course, made effective progress along many lines in addition to those concerned with coordination of engine design and fuel characteristics. Other subjects of research have included headlighting; highway safety; motor-truck and bus impact; front wheel alignment; riding comfort; and extreme-pressure lubricants.

Special Committees Meet Diversified Problems

Especially interesting, among Activity undertakings have been the combined efforts of the transportation and truck groups in the last few years. A suggested motor-vehicle code of size and weight restrictions, a tentative method for standardized rating of motor trucks, and the specific proposals for uniform vehicle operation accounting already referred to are but part of the fruits of vigorous committee programs sponsored by these divisions. After a year of trial, the standardized truck rating is again being subjected to committee scrutiny with a view to revision in the light of needs developed in its practical use.

Diesel and aviation groups, as previously mentioned, have been particularly active in fuel research matters, while passenger car activity sub-groups, through sponsored researches have developed definite means of rating and gaging automobile riding comfort.

The front-wheel alignment committee sponsored by passenger car and truck activity interests, having completed constructive work on specific questions over a period of years, is now wrestling with the new problems arising from the wide use of independent wheel suspension and other new design developments.

Members of the aircraft and aircraft-engine activities are among those that cooperated consistently with scientific and government agencies.

S.A.E. Has Wide Outside Contacts

As the recognized technical representative of the automotive industries, the S.A.E. participates widely in cooperative technical conferences with many other societies and governmental departments. It has a regular representative on the technical council of the American Standards Association, and coordinates systematically through committee representation with such groups as the American Society for Testing Materials, the American Transit Association, the Army and Navy Joint Standards Board, the Engineering Foundation, the American Society of Mechanical Engineers, the American Marine Standards Association, the American Bureau of Welding and others.

The Ordnance Advisory Committee of the S.A.E. cooperates steadily—and often confidentially—with the Ordnance Department of the U. S. Army.

A permanently functioning Military Motor Transport Advisory Committee of the Society cooperates with the Quartermaster Corps of the U. S. Army and has continued in peace time to extend practical advice and counsel of the sort which it began to give, at the request of the Army, at the time of the World War. Development of the design of the famous Class B truck was one of the outstanding war-time achievements of a cooperating group of S.A.E. engineers.

You have read recently in the newspapers of the formation of a committee headed by Newton D. Baker, former Secretary of War, to investigate and recommend improvements in the existing arrangements of the Army Air Service. Five members of the Society are performing a public service by serving on this committee.

For many years the Society membership has been well represented on the National Advisory Committee for Aeronautics. Excellent cooperation has always existed between this body and the Society.

Special recognition to the growing aviation industry has been given by the Society in scores of ways. Each year two awards are made for the most meritorious papers presented at Society meetings in the two chief branches of this industry —aircraft and aircraft engines. The Manly Memorial Medal is awarded to the author of the best paper relating to the theory or practice in design or construction of, or research on, aeronautic powerplants or their parts; the Wright Brothers Medal to the author of the best paper on aerodynamics or structural theory or research, or airplane design and construction.

Service to Members Growing

While the importance of a Society undertaking is not gaged by poundage or volume, there are certain routine operations in the Society's service to members which do assume an impressive magnitude, even in a year like 1933, which does not represent a peak in operations.

In 1933, for example, ten tons of preprints were requested by members. This involved more than a million impressions of the mimeograph stencil.

Three tons of JOURNALS each month and 16 tons of ROSTERS, HANDBOOKS and bound volumes of TRANSACTIONS each year are required to keep our membership in touch with the activities of the Society.

The telephone switchboard of the Society handles from 30,000 to 50,000 calls each year.

Attendance at the various meetings of the Society totals about 25,000 in a year. Attendance at Section meetings this year has been unusually high and may set a new record before the year is out.

Fundamentally, the S.A.E. is, of course, an association of American automotive engineers, but has just claims to being an international organization in many respects. Members of the Society live on every Continent of the world—even in Little America. Almost every nation of the world is represented on its foreign-member roll.

Statistics and specific examples are at best inadequate to express the full significance and potentialities of so vigorous an organization as the S.A.E. Its world wide importance unquestionably has been achieved because it has become a living medium through which the skilled efforts of thousands of professional men have found vital expression.

I should like to close by quoting a tribute to the Society, which is just as valid today as when it was written 23 years ago. The author was Senator W. J. Morgan. He said:

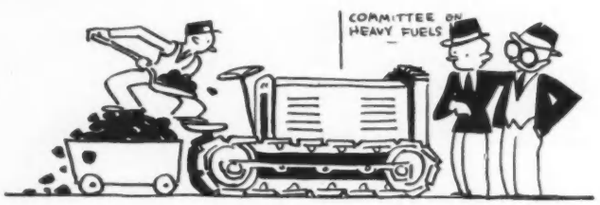
"A glance over the membership list confirms the belief that the best inventive and mechanical brains of the country, both in and outside of the automobile industry, are associated with them. These men have given of their time and services unsparingly, and it would be difficult to gage the value of the work they have performed. Many of them are at the head of vast industries, and it would be almost impossible to put a monetary value on their time, which has been so freely given to committee work.

"There has probably never been an industry which has received gratis from men outside its ranks so much benefit as has the automobile trade from these same manufacturers, and they have perhaps been inspired in their unselfish effort by the fact that the automobile has become a national benefit which will prove of untold value to every citizen."

Behind the Scenes With

Tractors and Industrial Power

A MEETING of the Tractor and Industrial Power Equipment Committee was held in Milwaukee April 19, in connection with the National Meeting sponsored by the Committee. It was decided that a subcommittee, with A. C. Staley of Chrysler as chairman, should outline a program of study of heavy fuels for tractor and industrial engines, with a view to stabilization of the fuel situation for more economical operation and to enable the tractor and industrial equipment manufacturers to adopt a rational program of engine development.



It was voted that members of the Tractor Committee should submit their views on extreme-pressure lubricants to Subcommittee-Chairman Staley so that he may communicate and cooperate with the S.A.E. Research Subcommittee more effectively on behalf of the tractor and industrial power equipment industry.

Tentative plans were laid down for holding two Tractor and Industrial Power Equipment Meetings annually, the next to be in December, if possible, in connection with a meeting of the American Society of Agricultural Engineers in Chicago.

Among the Committee members and guests present at the meeting were representatives of tractor and industrial equipment manufacturers, the petroleum industry, farm machinery manufacturers, parts producers, and the Department of Agriculture. Attendance at the Committee meeting numbered 20.

Fender and Body Clearances

MEMBERS of the Passenger-Car and Motor-Truck and Motorcoach Divisions of the Standards Committee have received copies of a request from a large chain company for opinions on possible action regarding standardization of minimum fender and body clearances required for use of chains over the tires of motor vehicles.

Road Tests on Fuels

THE program for cooperative road tests received the approval of the Cooperative Fuel Research Committee at its May meeting. Invitations to participate in the undertaking have been directed to all the leading automotive and petroleum companies in the U. S. and to interested groups in Canada, Great Britain, France and Germany.

July 9 has been set as the official starting date for the tests. The following Operations Committee has been appointed by Chairman T. A. Boyd of the C.F.R. Detonation Subcommittee, to be in charge of details arising in connection with the actual conduct of the tests and not specifically covered in the program: H. F. Huf, chairman, Atlantic Refining Co.; D. P. Barnard, Standard Oil Co. (Indiana); A. E. Becker, Standard Oil Development Co.; T. A. Boyd, General Motors Corp.; L. C. Lichty, Yale University; J. B. Macauley, Chrysler Corp.; T. B. Rendel, Shell Petroleum Corp.; and C. B. Veal, secretary, Society of Automotive Engineers, Inc.

Motor-Vehicle Operating Costs

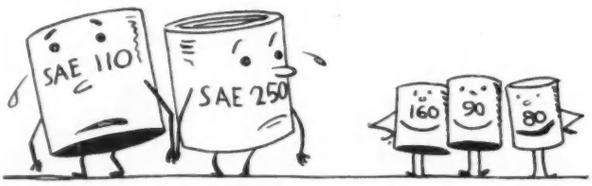
MEMBERS of the T & M Activity Committee and the Transportation Division of the Standards Committee have received for balloting three proposed extensions to the S.A.E. Recommended Practice on Uniform Motor-Vehicle Operating Cost Classification. The proposed extensions include several forms used in cost finding and accounting.

The N.R.A. Motor Trucking Code provides that the Code Advisory Authority shall determine a standard formula for uniform cost accounting. The present S.A.E. Recommended Practice (pp. 641 to 646, 1933 edition of the HANDBOOK) has been turned over to the Code Advisory Authority and it is expected that, if the recommended extensions are adopted by the Committees concerned, it will be of considerable assistance to the trucking industry in arriving at a uniform system for Code purposes.

Transmission Lubricants

THE Transmission Lubricants Subdivision, appointed at a Lubricants Division Meeting in Detroit last January, met March 5 in Washington.

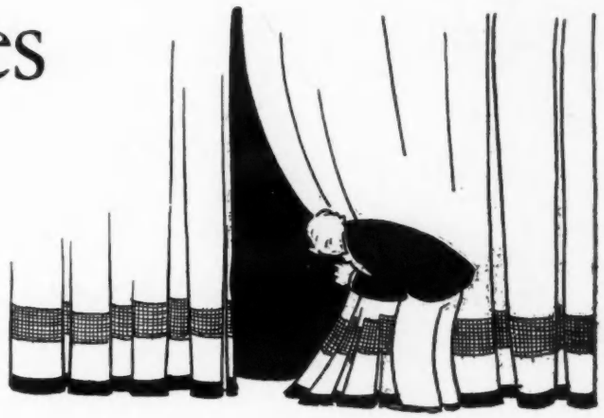
Questionnaires asking for data desired by the Subdivision have been prepared for circulation to oil companies and automobile manufacturers. The replies will be referred to Chairman Clayden for analysis and further consideration by members of the subdivision.



It was recommended that in writing instruction books for automotive equipment the term "transmission lubricant" be used in preference to transmission oil or gear oil, since the quoted term is the official S.A.E. designation for this class of product.

Discussion occurred as to the possibility of reducing the number of S.A.E. transmission lubricant classifications. It was the general feeling of the meeting that all practical requirements were met by S.A.E. 160, S.A.E. 90 and S.A.E. 80 which would eliminate S.A.E. 110 and S.A.E. 250. No vote was taken with respect to this subject.

the Committees



Extreme-Pressure Lubricants

W. S. JAMES, chairman of the Extreme-Pressure Lubricants Research Subcommittee, is scheduled to present a progress report of that Committee's work at the Summer Meeting and to demonstrate a machine for testing the load carrying capacity of extreme-pressure lubricants, recently constructed in the shops of the Studebaker Corp.

Iron and Steel Specifications

A BROAD review and revision of steel specifications and physical properties was undertaken at a 2-day meeting of the Iron and Steel Division of the Standards Committee held in Detroit on April 23 and 24. F. P. Gilligan, of the Henry Souther Engineering Corp., Hartford, Conn., is chairman of the Iron and Steel Division. The April meeting was attended by 19 members of the division and 20 guests. The total attendance represented almost every interested vocation on the question of steel specifications.

Appointment was made of a subdivision to give further consideration to the question of a uniform code for marking

steel bars relative to a request from the National Association of Purchasing Agents that the N.A.P.A. code on this subject should be endorsed or adopted by the S.A.E. A. H. d'Arcambal, Pratt & Whitney Co., is chairman of the subdivision. Other members were N. L. Deuble, Republic Steel Corp., and G. E. Knable, Carnegie Steel Co.

Several changes were proposed in the S.A.E. steel specifications covering chemical compositions. (S.A.E. HANDBOOK p. 254) In the carbon steels, S.A.E. 1000 series, tentative new numbers were added as follows: 1015A, 1020A and 1025A. The range of S.A.E. carbon steels was also extended to include proposed numbers 1055 to 1090 with a 15 point carbon range. Phosphorus inclusion for these steels were set at 0.040 max. and sulphur 0.050 max.

A new screw stock steel to be known as S.A.E. X1112 having a sulphur range of 0.20 to 0.30 was proposed, other contents being the same as S.A.E. 1112. In the 1300 series a new steel S.A.E. X1314 was added and in discussion of the composition of S.A.E. X1315 it was decided to revise the present sulphur range to read 0.075 to 0.150.

In the nickel chromium steel series a modified S.A.E. 3140 having a higher chromium was included.

A new steel for general commercial use to be known tentatively as S.A.E. 4245 was proposed. In discussing steels of the higher molybdenum type it was decided to recommend two types of composition; one to be specifically specified as an electric furnace steel and the other as basic open hearth steel. Tentative specifications were set up for both, but no numbers were assigned and a sub-division was appointed to consider their proper place in the 4000 series. A. L. Boegehold, General Motors Corp., was named chairman of the subdivision and B. H. De Long, Carpenter Steel Co. and J. B. Johnson, Wright Field, were appointed members.

A new steel to be known as S.A.E. 4135 was recommended.

In considering nickel molybdenum steel four new numbers were scheduled, S.A.E. 4620 for carburized gears of large section, S.A.E. 4640 for oil hardened transmission gears, S.A.E. 4815 and 4820.

In the silico-manganese series S.A.E. 9250 was deleted and S.A.E. 9255 having a carbon range of 0.50 to 0.60 was substituted. Tungsten steels in the 7000 series were retained as now printed in the HANDBOOK.

The present S.A.E. specification for steel castings is to be revised to bring it into accord with the current A.S.T.M. specification A154-33T for class B castings.

T. H. Wickenden, International Nickel Co. was appointed on a subdivision to report on the substitution of the new Brinell-Rockwell-Scleroscope hardness conversion tables and charts for adoption in place of the present tables appearing in the HANDBOOK. A subdivision was appointed to review and prepare revisions of the case hardening treatment data on pp. 272-274 of the HANDBOOK.

E. F. Davis, Warner Gear Co., was named chairman of this subdivision. W. J. Harris, Studebaker Corp., and O. W. McMullan, Timken-Detroit Axle Co. are the other members.

A subdivision of which W. J. Hilldorf, Timken Steel & Tube Co., is chairman and E. J. Janitzky, Illinois Steel Co., and Henry Wysor, Bethlehem Steel Co., are members appointed to study requests for Brinell and Scleroscope numbers on S.A.E. steels in the "as rolled" and "annealed" conditions.

A subdivision was appointed to study the question of the Society adopting standard specifications for cast iron of the plain alloy and electric furnace types. The subdivision will work in cooperation with A.S.T.M. Committee A-3. F. E. McCleary, Dodge Bros. Corp., is chairman, the other members being H. Bornstein, Deere & Co. and L. A. Danse, Cadillac Motor Car Co.

A subdivision was appointed to study the system of numbering S.A.E. steel compositions with a view to making them as consistent as possible throughout the series but with as

(*Continued on page 31*)

Papers Available in Mimeographed Form

UNTIL current supplies are exhausted, copies of the papers listed are available in mimeographed form at a cost of 25 cents per copy to members; and at 50 cents per copy to non-members.

Orders must be accompanied by remittance and should be addressed to Sessions Secretary, Society of Automotive Engineers, 29 West 39th St., New York, N. Y.

Barnard, D. P.
Butane Vs. Gasoline As an Automotive Fuel

Bleicher, C. E.
External Broaching

Bleicher, C. E.
Relative Merits of Precision Manufacturing and Correct Plant Layout to Accomplish Cost, Quality and Uniformity of Parts Production

Brettell, Clinton
How Economies in Motor Vehicle Operation Can Be Effected from an Operator's Standpoint

Briggs, Commander W., and Fox, M. L.
Body Noise

Broulhiet, Georges
Quality Objectives for Engineers—An official communication from the Societe des Ingenieurs de l'Automobile de France

Brown, W. C., and Roper, V. J.
The Well-Lighted Car

Bull, A. W.
Tire Noise

Cass, Robert
Future Trends in Motor Truck Transportation

Chandler, F. F.
Notes on Steering

DeSmet, E. C.
Planography—The New Science of Surface Design

Drake, H. W.
Problems of the Fleet Operator

Dutcher, F. H.
The Low Compression Ignition Oil Engine

Fisher, J. B.
Combustion Problems on Automotive Diesel Engines

Fisher, J. B., and Bower, L. L.
Trends in Tractor Engine Design

Fitzsimmons, J. T.
Problems and Tendencies in Electrical Equipment

Fodor, Nicholas
Hydraulics of High-Speed Fuel Injection

Foley, Hamilton
Manufacture and Magnetic Inspection of Hollow-Steel Propellers

Froesch, Charles
Some Aspects of Commercial Aviation

Frye, Jack
Aircraft Maintenance on Scheduled Service

Frye, Jack
New Airline Advancements: Maintenance and Operations

Geschelin, J.
Trends and Future Developments in Motor Truck Design

Haarz, W. G., Jr.
Beauty Sells Cars in 1934

Hazard, S., Jr.
Sound Absorption and Deadening

Horner, F. C.
Looking Forward in the Field of Transportation

Howard, H. H.
Some Diesel Tractor Problems

Hunsaker, J. C.
Airships for Commercial Purposes

Jacoby, E. R.
Practical Design Consideration of the Internal Combustion Engine Structure

Johnson, W. M.
A Résumé—and Some Conclusions

Kuttner, Julius, and Rippere, J. B.
Ignition Delay of Diesel Fuels Measured by Bouncing Pin in C.F.R. Engine

Lansing, R. P.
Starters for Diesel Engines

Lichty, L. C., and Carson, G. B.
Engine Friction Analysis

McCormick, Fowler
The Relation of Engineering to Manufacturing and Distribution in the Farm Implement Industry

Macauley, J. B.
Fuel Economy from the Engine Designer's Point of View

Mock, F. C.
Utilization of Heavy Fuel With Spark Ignition

Moss, F. A.
Air Conditioning and Relative Refinements for Auto Bodies

Norris, R. F.
The Automobile Motor Considered as a Sound Source

Northup, A. E.
Future Streamlining

Nutt, Arthur
Detonation Rating of Aviation Fuels

Orr, J. M.
Predetermined Operating Requirements for Purchasing Equipment

Peterson, C. D.
Multi-Range Transmissions

Pope, A. W., Jr.
The Hesselman Engine

Prescott, F. L.
High-Output Poppet-Valve Cylinders

Prudden, T. M.
Noise Treatment in the Automobile

Rendel, T. B.
European Automotive Diesels

Robertson, D. D.
Hydraulic Action in Piston Ring Design

Shepard, E. H.
The Economy Fallacy

Smith, C. W.
Comparative Tests of Pneumatic Tires and Steel Wheels on Farm Tractors in Agricultural Operations

Smith, G. W., Jr.
A Technical Education

Staley, A. C.
Requirements of Tractor and Diesel Engines

Stewart, J. P., and Risk, T. H.
Factors Affecting Oil Consumption

Teetor, R. R.
Conformity of Cylinders, Pistons and Rings

Thee, W. C.
Standardization of Military Motor Equipment

Treiber, O. D.
Factors in Automotive Diesel Development

Veal, C. B.
Mind or Micrometer

Wheeler, P. R.
Human Engineering

White, L. T.
Why Waste Fuel Through the Exhaust?

Zucrow, M. J.
Some Experiences with Heavy Fuel Equipment for Spark Ignition Engines

Relation of Headlamp Construction to Headlamp Roadway-Performance

By L. M. K. Boelter[1], D. D. Davis[2], W. L. Fons[3], and D. O. Rusk[4]

HEADLAMP construction is presented in summarized form, twelve needful factors being stated by the authors. Accelerated mechanical tests, which are designed to give within a few days results of what may be expected to take place after several years of road service, are conducted in the Headlight Laboratory of the University of California. These are described and illustrated under the headings: Vibration, durability, moisture, dust and electrical insulation, and the results are stated. A few correlation tests are commented upon. Headlamp vibration is treated at length, together with an analysis of headlamp vibration-characteristics, and a differentiation is made between vibration due to the engine and that due to roadway shocks.

Measurement of headlight glare upon the roadway was made by obtaining continuous records of the illumination of the driver's eye from opposing cars or other equipment, the apparatus used including a photoelectric cell mounted inside the windshield in a direct line with the driver's eyes, an amplifier specially designed to cover the range of illumination and an oscillograph for obtaining a photographic record. Partial results of these tests are given. The general conclusions reached are set forth in six divisions, the last being that 0.07 ft-candle at 100 ft. is indicated as a criterion of glare.

DURING the last few years, rapid strides have been made by the industry in improving the mechanical construction of headlamps. Observations on the Headlight Situation in California in 1928, by Lawrence O'Donnell, Erskine Fellow at the University of California[5], revealed the importance of proper mechanical construction.

Unfortunately, later data are not available to the authors. However, a twenty-day experimental drive by the California Highway Patrol between Nov 2 and Dec. 10, 1930, in California, resulted in 14,213 arrests for one headlight out or the rear light out. Further, a study of the 1933 Statistical Report of the California Department of Motor Vehicles reveals a correlation of accidents in which faulty headlamps were a contributing factor; as shown in Table 1.

The values in Table 1 indicate that the ratio of accidents due to faulty headlights is increasing slightly. The number of vehicles therein considered represents but 0.4 per cent of all the vehicles involved in accidents and approximately 1/1000 of the total registration of the state. It obviously will be impossible to discuss headlamp construction in detail in this paper. A brief summary will be presented in the following paragraphs.

Inspection of typical headlamp-construction reveals the following factors as pertinent to proper mechanical construction:

(1) The headlamp support—indicating all supporting parts from the saddle to the frame of car—should be rigid. Practice a few years ago often placed the headlamp either upon an excessively elastic fender or upon the fender bracing. The rigidity of the fenders has been increased so that this method of mounting compares favorably with independent mounting.

(2) The method of fastening a headlamp to its support will cause a loose headlamp if a leather or rubber filler is used which ages with time and the weather.

(3) The rigidity of the housing should be such that it will not break around the saddle. In late construction, the lamp housing has been strengthened and lightened by using appropriate structural sections. Adequate saddles and pads are being provided.

(4) The door should fit snugly so that the gasket will be partially protected from the weather.

(5) Strong and elastic door-clamps which will maintain proper and uniform pressure upon the gasket are desirable.

(6) The thickness of the gasket, as well as its perimeter, are important design considerations because cork, rope or felt, the materials usually used, are not impervious to moisture. Alternate saturation and drying of the cork or felt gasket may gradually cause deadening of the material. Unless the door clamps are properly designed, the gaskets will become leaky and admit both dust and moisture. Provision of a groove or clamping strip has greatly improved the effectiveness of the gasket.

(7) The practice in former years, of holding the lens by means of clamps and screws, has been almost entirely super-

[This paper was presented at the 1934 Annual Meeting of the Society, Detroit.]

[1] Associate Professor of Mechanical Engineering, University of California.
[2] Assistant Professor of Electrical Engineering, University of California.
[3] Assistant in the Photometry Laboratory, University of California.
[4] Former Assistant in Mechanical Engineering, University of California.

[5] See S.A.E. JOURNAL, June, 1928, p. 684: The Headlight Situation in California, by L. M. K. Boelter.

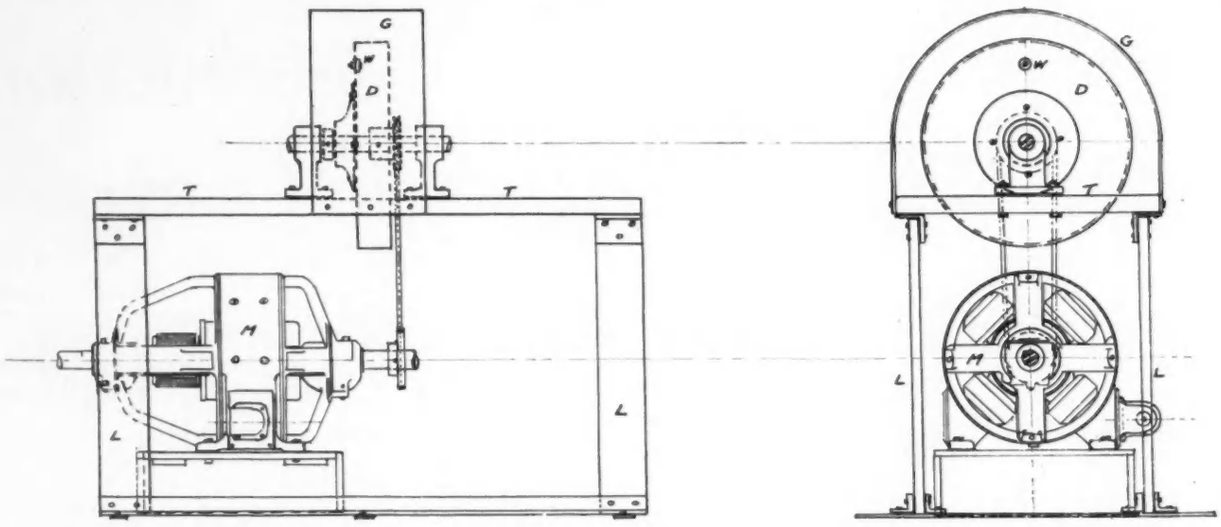


Fig. 1—Low-Frequency Vibration-Test Apparatus

The duration of the test was 8 hr., the devices being attached to the table top in the same way as when mounted on a car. The number of vibrations per minute when resonance begins depends upon the device and the mounting, the amplitude of the table-top vibration being about ⅛ in.
A steel drum of 16¼-in. diameter is represented at *D*; a guard, at *G*; wooden legs ¾ x 3¾ in., at *L*; a 1-hp. variable speed motor, at *M*; the wooden table-top 21 x 43 in., at *T*; and a small weight to unbalance the drum, at *W*.

seded by the use of several leaf or wire springs which are fitted into notches placed circumferentially inside of the door rim.

(8) The reflector is usually supported by an adequately designed flange. It is usually held in position by screws or dowels. Movable reflectors required liberal design of supports and actuating mechanism.

(9) A drain for the housing should be provided. Water may collect due to leakage between the door and housing, through the lead-in-wire inlet, or around the focusing or tilting screws. Also, moisture will condense upon decrease in temperature; for example, due to turning out of the lamp. The lens-reflector combination should provide a vaporproof compartment.

(10) In spite of the precautions resulting from adequate design under items (6) and (9), it is desirable to protect parts against corrosion. Steel springs may be mentioned as having been overlooked in this connection.

(11) The focusing mechanism has been eliminated in the latest practice because of the narrow production-variation limits of modern lamp bulbs. The sockets are therefore reasonably rigidly placed with respect to the reflector and thus are eliminated as a cause of mechanical trouble. If an external focusing screw is provided and the socket is placed in the reflector, the mechanical linkage between the screw and the socket, unless loosely coupled, will be a source of stress upon the reflector, especially when the socket tends to bind in the socket guide. Stripping of the focusing screw was a common difficulty.

In some designs, the socket guide is fastened to the housing and, unless proper clearances are allowed, a stress will be transmitted to the reflector due to distortion of the housing. Late designs have included "filament-positioning mechanisms" which are subject to wear and looseness due to joints in the linkage; but these defects will, in general, only cause a vertical movement of the beam since the distance of the filament from the vertex of the reflector remains practically unchanged.

(12) In the fixed-focus construction, the socket is fastened to the reflector and thus the only motion possible will be between the bulb base and the socket. The pins and springs of the bayonet socket in the older types were reasonable causes of difficulty, either because of loss of elasticity of the springs due to heating caused by a poor electrical contact or as a result of fatigue due to continued vibration. Modern construction involving one large helical spring, a small helical spring used as a band, or two external springs eliminating the pins and screws, are valuable contributions in the direction of reducing the number of "lights out." The pins were subject to corrosion and consequent sticking. The use of prefocused bulbs has eliminated the possibility of motion between the bulb and the reflector.

(13) Lamp-filament sag upon heating is due to the static or dynamic loading. Modern filament design has practically eliminated this problem.

Table 1—Fatal and Non-Fatal Accidents Due to Faulty Motor-Vehicle Equipment

Year	Vehicles with Faulty Headlights	Total No. of Vehicles	Ratio
1930	206	1,468	0.140
1931	286	1,570	0.182
1932	333	1,768	0.188

Mechanical Tests

Accelerated mechanical tests, which are designed to give within a few days results of what may be expected to take place after several years of road service, are conducted in the Headlight Laboratory of the University of California as follows:

(*A*)—*Vibration*.—See Figs. 1, 2 and 3.

(1) For low-frequency vibration, see Fig. 1;

(*a*) The device is mounted, as nearly as possible in conformity with recommended car-mounting on the free end of a short cantilever beam which is fastened to the vibration table.

(*b*) The length of the cantilever beam and the motor speed are adjusted so that resonance conditions are obtained for the device and mounting at a frequency between 1200 and 1800 cycles per min.

(*c*) The table and device amplitudes are adjusted to approximately ⅛ in. and from ¼ to ¾ in. respectively.

(*d*) The vibration is continued for 8 hr. or until destruction of the device occurs.

(*e*) Upon completion of the test, inspection of the device is made for wear, distortion and breakage.

(2) For high-frequency vibration, see Figs. 2 and 3.

(*a*) The device is mounted on the high-frequency vibration-stand in a way as nearly as possible in conformity with the recommended car-mounting.

(*b*) The vibration frequency is adjusted so that resonance is obtained for the part—or parts—of the device which appear weakest from a vibration-durability standpoint.

(*c*) The vibration is continued for 8 hr., or until partial destruction of the device occurs.

(*d*) Upon completion of the test, inspection of the device is made for wear, distortion and breakage.

(*B*)—*Durability.*—For devices which move, or contain moving parts. See the durability test-stand shown in Fig. 4.

(*a*) Devices are set up in a manner similar to that of an installation on a car and are operated mechanically.

(*b*) The rate of operation may be equal to normal operating speed or it may be accelerated.

(*c*) Tests at normal operating speed are continued until one million cycles of operation are completed. For accelerated tests, the total number of operations are made approximately equal to one million multiplied by the square of the ratio of the normal speed to the accelerated speed.

(*d*) Minor failures are repaired and operation continued to the desired limit, if possible. Upon completion of the test, inspection of the device is made for wear and breakage.

(*C*)—*Moisture.*—Fig. 5 shows the moisture-test apparatus.

(*a*) The device is mounted in the tank and rotated at 1.35 r.p.m.

(*b*) Eighty cu. ft. of free air per min., 0.7 cu. ft. of water per hr., in the form of a fine spray, and enough low-pressure steam to increase the tank exhaust-temperature to 90 deg. fahr., are forced through the tank.

(*c*) The device is placed in the path of the mixture for an 8-hr. period.

(*d*) The quantity of water collected on the reflector, on the inside of lens surfaces and in the space between these two surfaces, is observed.

(*D*)—*Dust.*—Fig. 6 shows the dust-test apparatus.

(*a*) The device is mounted in the tank and rotated at 1.35 r.p.m.

(*b*) Dry cement-dust of known reflection factor in the tank is agitated by a three-bladed impeller driven at 1725 r.p.m.

(*c*) The device is placed in the dust tank for an 8-hr. period.

(*d*) The reduction of transmission and reflection factor due to dust collected inside the lens-reflector compartment is determined.

(*E*)—*Electrical-Insulation Test.*—The electrical insulation between conductors and ground with the bulb removed is measured with a Megger—500 volts—both before and after the moisture test.

Laboratory-Test Results

The results of the laboratory mechanical tests on various devices submitted, when tests were begun in 1929, show large variations. Auxiliary lamps—distinguished from headlamps by their type of service and smaller size—showed the following variations. Many of the devices submitted in this category used no gasket.

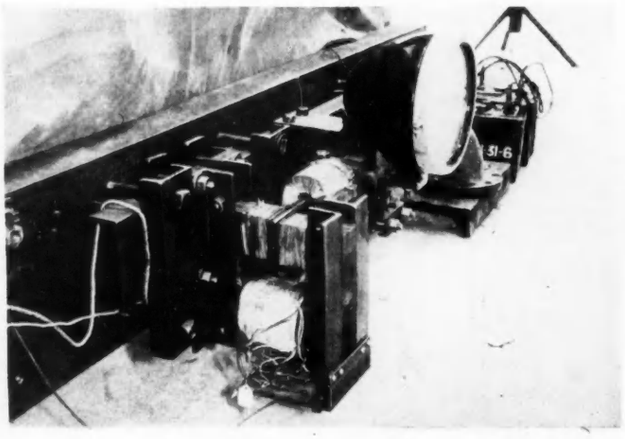
Vibration Test.—The low-frequency vibration-test resulted in (*a*), broken lamp-brackets; (*b*), loosening of reflector supports, that is, for a reflector fastened in a door; (*c*), broken housings near the area of saddle attachment; (*d*), broken lenses because of proximity to screws; (*e*), disconnected or broken electrical lead-in wires; and (*f*), lenses being rotated out of position.

Moisture Test.—A slight condensation, to 35 cc. of moisture, was collected in 8 hr.

Dust Test—From no reduction to 35-per cent reduction of reflection and transmission factor resulted from 8 hr. of exposure.

Insulation Test.—All devices were found satisfactory. For the dry devices, the insulation resistance varied from 3 to 100 megohms.

The same mechanical tests performed on headlamps showed much better performance. The moisture and dust leakages were low, as all devices had been provided with gaskets; and the vibration tests only slightly disarranged the parts, the construction being fairly rigid. The results of dust and moisture tests for the period from Jan. 1, 1931 to Feb. 1, 1934, inclusive, are listed in Table 2.



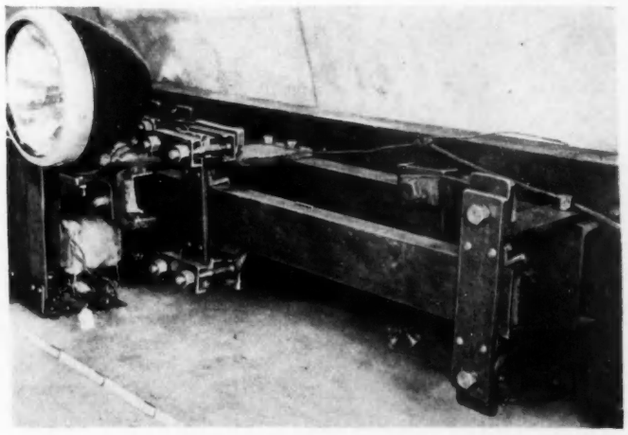


Fig. 2—High-Frequency Vibration-Test Apparatus

Table 2—Results of Dust and Moisture Tests on Headlamps; January, 1931, to Feb. 1, 1934

Year	No. of Devices	Reduction of Transmission and Reflection Factor Due to Dust, Average	No. of Devices Listed in Col. 2 for Which the Moisture Test Yielded Excessive Leakage
1931	9	3.4	1
1932	7	3.2	2
1933	10	2.8	2
1934	5	2.7	1

In addition to the devices listed in Table 2, several devices were tested each year for which the reduction of transmission and reflection factor was from 9 to 14 per cent and the corresponding moisture-leakage was also excessive. It may be concluded from the data upon which Table 2 were based that poor dust-leakage performance also results in excessive moisture-leakage; the table also shows a slight improvement in construction during the four-year period.

A Few Correlation Tests

Laboratory tests for a headlamp of substantial construction were run in the order of 8 hr. of vibration at 1900 cycles per min., 8 hr. of moisture test and 8 hr. of dust test; the cycle was then repeated. The devices were photometered before and after each individual test, and were dried and cleaned after the photometric test which followed the moisture and the dust tests, respectively. The results of three 8-hr. cycles yielded the following conclusions:

(1) A trace of water vapor and water—similar to a light dew in amount—was collected each 8-hr. period.

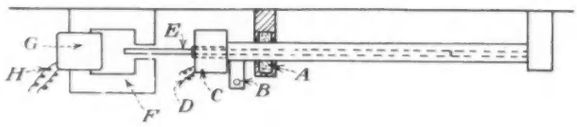
(2) The dust infiltration for each 8-hr. period caused a 4 to 5 per cent reduction of reflection and transmission factor until the gasket became water-soaked. The dust infiltration was much less for the water-soaked gasket. The gasket was not dried each time.

To illustrate the effect of dust infiltration upon roadway illumination, test results from two pairs of headlamps are submitted. The results of photometric distribution tests for the headlamps of a Model-236 Packard follow. The headlamp gasket was leaky and one lens edge was chipped. The reflectors and lenses had been cleaned one year previously. As taken from the car, the average roadway illumination was 75 per cent of the average obtained after cleaning the lenses and polishing the reflectors. Cleaning only the outside of the lenses increased the average from 75 to 78 per cent. Similar results for the headlamps of a 1926 Buick follow. The headlamps were standard equipment, well gasketed, were equipped with "Eureka Lite Guards," and had not been opened for four years. As taken from the car, the average roadway illumination was 79 per cent of the average obtained after cleaning the lenses and polishing the reflectors. Cleaning the outside of the lenses only increased the average from 79 to 82 per cent.

Vibration of the Headlamp

Observation of the behavior of the spring and weight shown in Fig. 7 yields the fact that, if the weight is displaced slightly and the exciting force removed, the weight will oscillate at a certain fixed frequency. This frequency is the natural frequency of the mass-spring system if damping is small. A similar phenomenon may be noted if a headlamp, mounted upon its support, is plucked and released. The natural frequency, f, of an equivalent mass-spring system corresponding to the headlamp system, depends upon the moment of inertia, I, of the headlamp as well as upon the rigidity, K, of the support and housing. It may be expressed as, $f = \frac{1}{2}\pi\sqrt{(K/I)}$

If the connecting rod—crank mass-spring system shown in Fig. 8, is operated, it will be observed that the amplitude—one-half of the total motion—of the weight will vary with the rate at which the crank is turned. This rate is called the forced frequency. For low crank-speeds it will be observed that the weight moves through a distance which is equal to the distance traveled by the crosshead. If there were no air



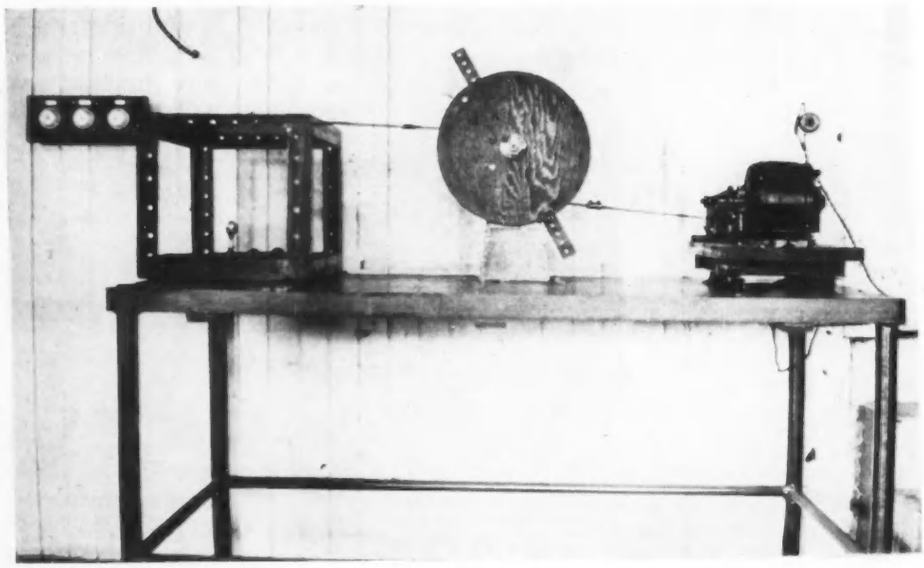


Fig. 3 *(above)*—**Headlamp Mounting for Steady Forced Vibrations at High Frequency**

An adjustable rubber mounting, of beam length, is indicated at *A;* a headlamp mounting, at *B;* a direct-current coil having 1500 turns of No. 18-gage wire, at *C;* a lead to a rheostat and a 110-volt direct-current, at *D;* a 5/16 x 2¼-in. tempered-steel reed—the length being adjustable for varying resonance frequency—at *E;* a 1 x 2¼-in. laminated core, at *F;* an alternating-current coil having 75 turns of No. 14-gage wire, at *G;* and a lead to a 1 kw. 500-cycle generator, directly connected to a direct-current variable-speed motor, at *H.*

Fig. 4 *(left)* — **Durability Test-Stand**

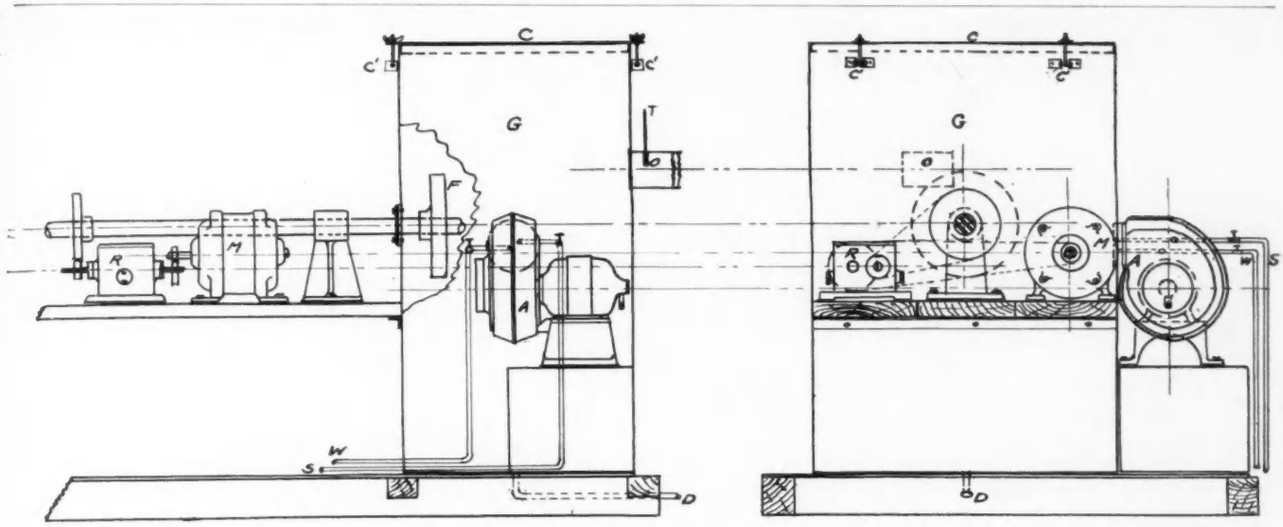


Fig. 5—Moisture-Test Apparatus

The duration of the test was 8 hr. The quantity of water collected was determined. The flow of air, water and steam were adjusted for 90-deg. fahr. discharge.
An air blower of 80 cu. ft. per min. free-air discharge is shown at *A;* a wooden cover, clamped with clamps *C* and *C*1, at *C;* a drain, at *D;* a flange to which devices are attached, its speed being 1.35 r.p.m., at *F;* a galvanized-iron tank 18 x 24 x 32 in., at *G;* a motor to turn flange *F*, at *M;* a 3 in. x 4 in. opening to the atmosphere, at *O;* a 400:1 reduction gear, at *R;* a ¼-in. steam-line, at *S;* a thermometer, at *T;* and a ⅛-in. water-line with a No. 72 spray nozzle, at *W*.

friction or internal resistance, as the crank-speed is increased the amplitude of the weight *W* would increase and become infinite when the forced frequency is equal to the natural frequency. For still higher crank speeds the amplitude would decrease until, finally, at very high speeds, the weight would remain stationary. These results are shown graphically in Fig. 9, as Curve *A*. The effect of the damping, that is, air resistance and internal friction, assumed viscous—velocity damping—is illustrated by Curves *B* and *C*. The point at which the forced frequency equals the natural frequency is called the resonance frequency. The effect of damping is to reduce the amplitude at resonance to a finite amount; the greater the damping is, the less is the amplitude at resonance. It will be observed from the curves that, for forced frequencies equal to several times the natural frequency, the amplitude is reasonably independent of damping and becomes small.

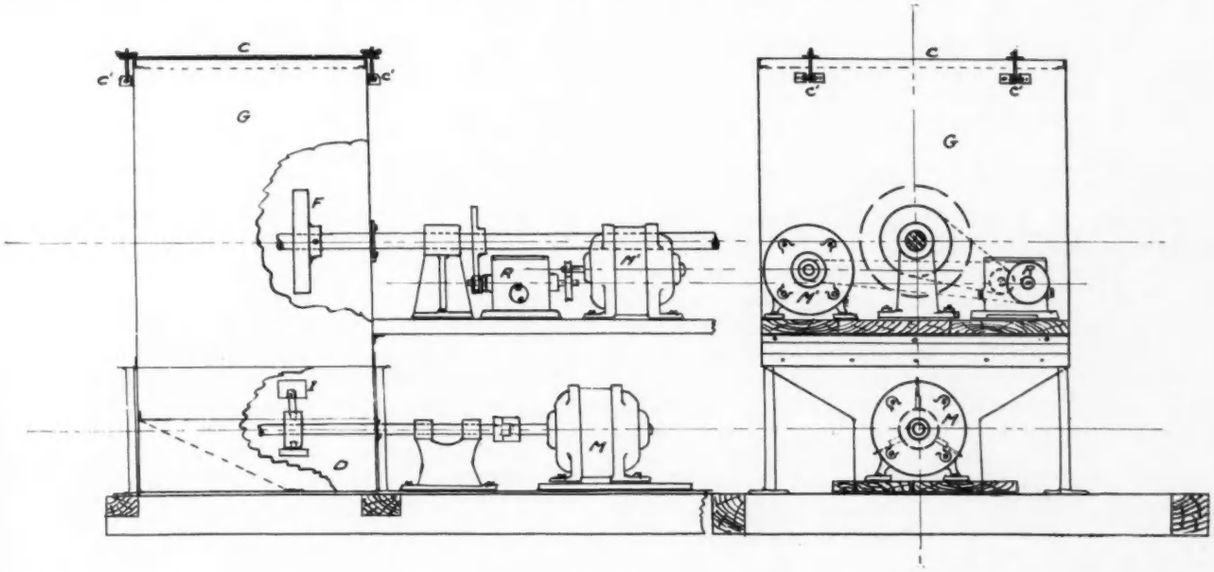


Fig. 6—Dust-Test Apparatus

The duration of the test was 8 hr. The reduction of reflection and transmission factor were measured.
A wooden cover—clamped with clamps *C* and *C*1—is indicated at *C;* cement dust, kept dry by calcium chloride, at *D;* a flange to which devices are attached—its speed being 1.35 r.p.m.—at *F;* a galvanized-iron tank 18 x 24 x 32 in., at *G;* a three-blade impeller, which agitates the dust, at *I;* a motor which revolves the impeller at a speed of 1725 r.p.m., at *M;* a motor which revolves flange *F*, at *M*1; and a 400:1 reduction-gear, at *R*.

Fig. 7—A Simple Mass-Spring System

Fig. 8—A Simple Mass-Spring System Subjected to Forced Vibration

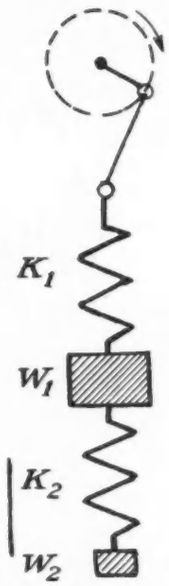


Fig. 10—Compound Mass-Spring System Subjected to Forced Vibration

Thus far, a single weight which is constrained to move along a straight line has been considered; but vibrating systems are more often made up of several weights elastically connected, the resulting motion[6] being usually very complicated. The method described in Holzer, *Drehschwingungen,* may often be employed to solve complicated dynamical systems. The motion of any one weight will be made up of the superposition of several of the simpler vibrations already described.

For example, the motion of W_2 of the elastically coupled system shown in Fig. 10 will be made up of the motion of W_1 relative to the fixed support plus the motion of W_2 relative to W_1. If this system vibrates in such a manner that a constant ratio is maintained between the displacement of W_1 and the displacement of W_2, both measured from their respective positions of equilibrium at the same instant of time, the vibration is called a principal mode and each weight executes a simple harmonic motion. There are two principal modes for the system shown in Fig. 10, one when both weights are always moving in the same direction and the other, of higher frequency, when the weights are always moving in opposite directions. Resonance conditions for such an elastically coupled system will occur when the forced frequency coincides with the frequency of one of the principal modes, and large amplitudes will result.

In the case of automobile headlamps, the exciting forces are caused by the engine, by unbalanced running-gear and by road shocks. The unbalanced forces of the engine may be thought of as the side thrust of the pistons on the cylinder walls, the explosion and inertia torques, and the pitching couples. Fig. 11 shows the variations of side thrust of one piston on its cylinder wall. This curve repeats itself every two revolutions of a four-stroke-cycle engine. Any periodic curve may be represented by the addition of simple harmonic curves of proper amplitude and having frequencies which are integral multiples of the frequency with which the given periodic curve repeats itself. The result of an analysis is expressed as a Fourier series. The variations shown in Fig. 11 may therefore be considered to be made up of simple harmonic terms having frequencies equal to one-half engine-speed, engine-speed, and integral multiples of one-half engine-speed.

Similar analysis of the other unbalanced engine-forces shows that there may be transmitted to the headlamps exciting forces at frequencies of one-half engine-speed, engine-speed, and integral multiples of one-half engine-speed. These forces are continuous and exist when the engine is running.

Vibration of the headlamps causes wear or fatigue and resultant permanent distortion which affects the parts of the headlamp in the following manner:

(1) Distortion of housing, may cause:

(*a*) Distortion of the reflector and resultant disturbance of the light distribution

(*b*) Breakage of the housing at the saddle

(*c*) Leakage of moisture or dust around a door for the types not gasketed between reflector and lens

(2) Lens clamp-springs may break.

(3) Lenses may be broken.

(4) The gasket may be aged at an excessive rate due to weathering and vibration. If not clamped properly, alternate compressions and expansions of the gasket result.

(5) A weak reflector may be distorted near the socket because of relative motion due to the inertia of the socket and lamp. Approximately 8 per cent of the light which is received from a point source by an 8-in., 1¼-in.-focal-length reflector is collected on the reflecting surface between the base of the bulb and a concentric circle of the same diameter as the bulb.

(6) The socket guide, or socket, in the reflector, may be loosened if not rigidly fastened.

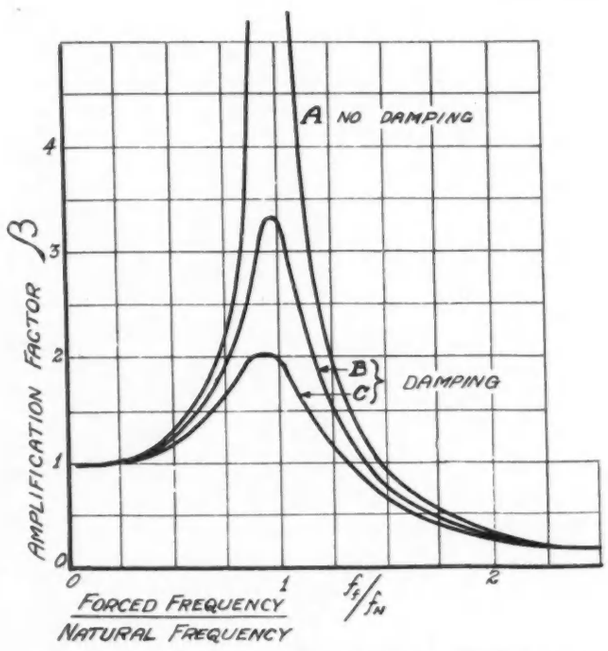


Fig. 9—Curves Showing the Relation of Amplitude of Vibration of the System Shown in Fig. 8 to the Ratio: Forced Frequency Divided by Natural Frequency; That Is, f_f/f_n

[6] See Vibration Problems in Engineering, by S. Timoshenko; D. Van Nostrand Co., Inc., 1928.

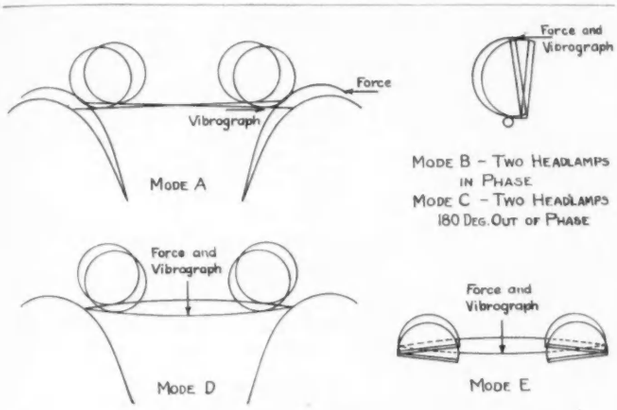


Fig. 12—Illustration and Definition of the Different Modes of Headlamp Vibration

(7) The lamp base in the socket may be loosened by the wear of the pins or slots and fatigue of the springs (continued vibration at resonance).

(8) Sag of improperly designed filaments may result.

(9) The electrical circuit to the socket may be broken or grounded.

For each elastic part of the headlamp system there exists a frequency for which amplitudes and stresses are a maximum.

Headlamp Vibration-Characteristics

Exciting forces due to unbalanced engine-forces, unbalanced running-gear and rough roads, are transmitted from the car frame to the headlamps through the headlamp supporting members. The headlamps and their supporting members constitute a vibrating system with many degrees of freedom.

The simpler, lower-frequency modes of vibration which have been studied are shown in Fig. 12. This is for the typical supporting system with the headlamps mounted on the fender tie-bar. In Mode A, the two front fender-supports are considered to be vibrating as cantilever beams and causing lateral vibration of the headlamps. Modes B and C define angular vibrations of the headlamps in the longitudinal plane of the car, about the fender tie-bar as a center. For Mode B, both headlamps are in phase and, in Mode C, the two headlamps are 180 deg. out of phase. Modes D and E represent vibrations of the fender tie-bar causing a small movement of the headlamps. Modes B and C have been studied theoretically[7] by D. O. Rusk, at the University of California. A simplified system illustrating these modes is shown in Fig. 13, which assumes that the fenders are rigid in torsion about the axis *A—A*. The calculated curves in Fig. 14 illustrate a typical solution, that is, the combined motion of Modes B and C.

Each of these modes—A, B, C, D and E in Fig. 12—was studied from vibrograph records of damped free-vibrations. The vibration was started by applying a known force and suddenly releasing it. The location and direction of application of the force and vibrograph are indicated by arrows for each mode. Fig. 15 shows the Geiger vibrograph used; Fig. 16, the device for its attachment; Fig. 17, the device for the application of the force; Fig. 18, a sectional drawing of the Fig. 17 device; and Fig. 19, the device for attaching the vibrograph pen to smooth surfaces, such as to the headlamp. All motion was measured relative to the car frame.

[7] See Some Vibration Characteristics of Automobile Headlamps, by D. O. Rusk, a M.S. Thesis on file in the University of California Library.

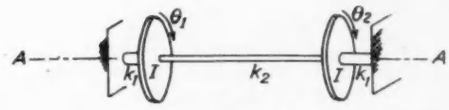


Fig. 13—Simplified System for Illustrating Vibration of Headlamps in Modes B and C of Fig. 12

The vibrations for a 1932 Model-X car, shown in Fig. 20, indicate some of the difficulties experienced in obtaining records of each mode separately. Curve 1 was obtained by attaching the vibrograph to the top of one headlamp and applying the force to the same headlamp. Curve 2 was obtained with the force applied to one headlamp and the vibrograph attached to the other headlamp. Both curves are complicated vibrations, with Modes B and C predominating. From the mathematical analysis of the simplified equivalent system, consisting of the torsional vibration of two discs mounted on a torsion member fixed at its two ends, the equivalent constants for Modes B and C were determined from these two curves. Refer again to Figs. 13 and 14. The curves for Modes A, D and E, show the respective modes predominating, but the motion in each case is complex.

Table 3 shows the constants for five cars for Modes A, B, C, D and E. All of the natural frequencies shown are within the range of the predominating unbalanced engine-forces that occur at ordinary driving speeds.

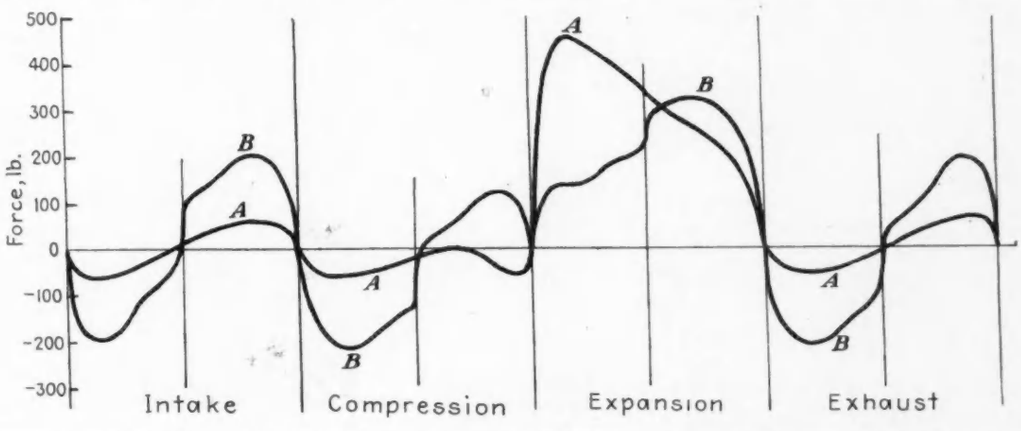


Fig. 11—Typical Curves Illustrating the Reaction of a Piston Against Its Cylinder Wall, Low Speed Being Represented by Curve *A* and Moderate Speed by Curve *B*

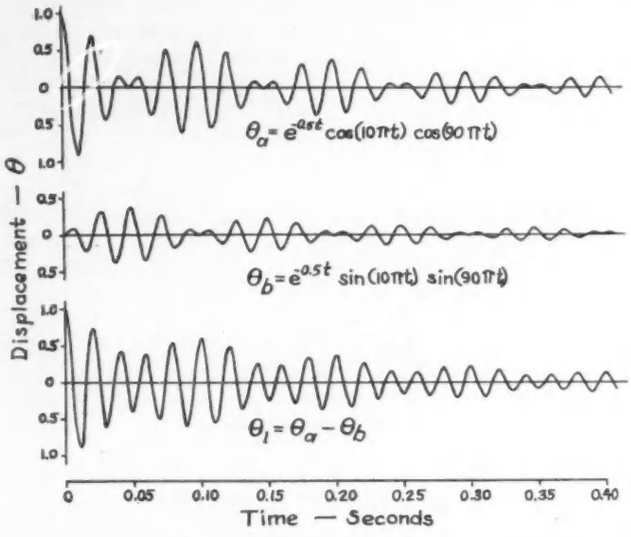


Fig. 14—Calculated Curves Showing a Typical Solution of the Combined Motion of Headlamp Vibration; Modes B and C of Fig. 12

A large difference is noticeable in the equivalent moments of inertia of the headlamps on different cars, but the corresponding equivalent spring-constant in each case keeps the natural frequency at about the same order of magnitude. These data are amplified for other cars in the thesis of D. O. Rusk, already cited[7]. Vibration, in Modes B and C, causes the greatest disturbance in the distribution of light upon the roadway.

It may be seen that the equivalent moment of inertia of the vibratory mass in Mode B is approximately twice that in Mode C, which serves as a check on the calculations. The equivalent moments of inertia and equivalent weights were computed from the measured frequencies and spring constants. The time constant n, is defined in the damping multiplier ε^{-nt} where (ε) is the Naperian base, and t is the elapsed time in seconds. In curves of Fig. 14, $n = 0.5$

The engine speeds of Car 1932-X corresponding to resonance in Mode E may be computed in the following manner. The natural frequency f, is 26 cycles per sec. or 1560 cycles per min. The half-order harmonic repeats itself every two revolutions in a four-stroke-cycle engine; therefore, resonance will exist at an engine speed of 1560 x 2, or 3120 r.p.m. Similarly, for the higher harmonics, we have:

Order of Harmonic	Engine Speed for Resonance, R.P.M.
1/2	3,120
1	1,560
3/2	1,040
2	780
5/2	624
3	520
7/2	445
4	390
•	•
•	•
m	$(f \times 60)/m$
•	•
•	•

Table 3—Constants of the Headlamp System for Modes A to E for Five Cars

Car Model	Natural Frequency, f, Cycles per Sec.	Equivalent Moment of Inertia at Headlamp Base, I, Slug-Ft².	Equivalent Spring Constant at Headlamp Base, K, Lb.-Ft. per Radian	Time Constant n, Sec.⁻¹
		Mode B		
1932-X	29	0.061	2,000	6
1928-Y	43	0.042	3,000	7
1932-Y	43	0.071	5,000	12
1928-Z	29	0.14	4,600	5
1932-Z	29	0.33	11,000	6
		Mode C		
1932-X	34	0.036	1,600	6
1928-Y	49	0.019	1,800	7
1932-Y	44	0.033	2,500	12
1928-Z	32	0.073	2,800	5
1932-Z	43	0.12	8,500	6
		Mode A		
1932-X	19	65	2,400	5
1928-Y	15	110	2,500	5
1932-Y	33	36	4,000	9
1928-Z	25	67	4,300	8
1932-Z	21	110	5,300	4
		Mode D		
1932-X	46	3.6	790	6
1928-Y	54	4.0	1,200	8
1932-Y	79	2.2	1,400	21
1928-Z	88	1.2	970	16
1932-Z	110	3.0	3,500	12
		Mode E		
1932-X	26	6.0	430	5
1928-Y	104	1.7	1,800	22
1932-Y	99	1.0	100	23
1928-Z	29	6.9	590	6
1932-Z	34	20.0	2,400	6

Fig. 15—The Geiger Vibrograph

In general, the second harmonic and multiples thereof will cause appreciable exciting forces in four-cylinder engines. Vibration in Mode E therefore can be expected at 780, 390, . . . r.p.m. Calculations for the other modes listed, or for any other part of the elastic system, may be made in a similar manner.

Headlamp Vibration Due to the Engine

Fig. 21 shows the amplitude of vibration of the headlamps on a 1928 Model-Y car with the vibrograph attached as for Modes B and C, as shown in Fig. 15. The oscillation was caused by the engine, running without load. Between 600 and 1600 r.p.m., the frequency of vibration corresponded to the second harmonic of engine speed. From 2200 to 3300

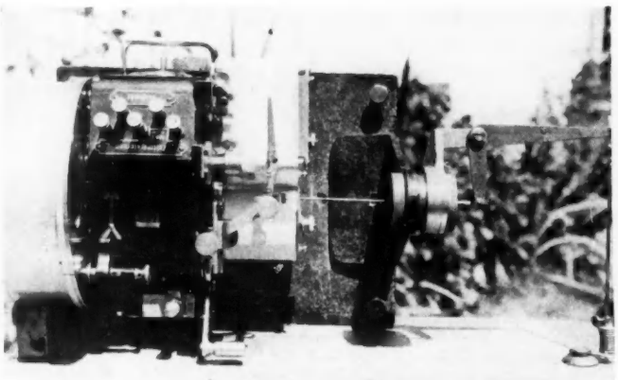


Fig. 16—Device for Attaching the Geiger Vibrograph

r.p.m., the frequency of vibration corresponded to the fundamental of engine speed. Between these ranges the frequencies of both the fundamental and the second harmonic were obtained. Resonance conditions for Modes B and C are marked. The peak occurring at 30 cycles per sec. was for another mode involving the vertical vibration of the fenders as well as the vibration of the headlamps, and for which no further data were obtained. The absolute amplitude of vibration of the car frame is shown by the dotted lines for the vertical and sideways directions. The longitudinal movement of the car frame was too small to indicate on this graph.

These headlamps were 9 in. in diameter; so, a horizontal movement at their top of 0.05 in. relative to the base, corresponds to the vertical movement of the light beam of 13 in. at a distance of 200 ft. in front of the car. The maximum amplitude, therefore, corresponds to approximately a 13-in. vertical-displacement of the light beam from its normal position at 200 ft. and gives a total movement of 26 in. This motion occurs at an engine speed corresponding to 33 m.p.h.

Headlamp Vibration Due to Roadway Shocks

Roadway disturbances are distinguished from engine excitation by the fact that the excitation is usually not periodic. If it should be periodic, due to corduroy roads, the frequency is usually relatively low.

To measure the effect of roadway unevenness upon headlamp motion, the vibrograph was attached to the 1928 Model-Y car approximately as shown in Fig. 15. The curves shown in Fig. 22 resulted from coasting at about 27 m.p.h. over roads of various surface characteristics while the engine was not running. Only the rough roads caused serious disturbances; but the curves serve to indicate the continuous vibration of the headlamps while the car is in motion. The headlamp motion indicated in Fig. 22 is with respect to the car frame. The headlamp beam also oscillates due to the motion of the car frame with respect to the ground. The car-frame motion causing oscillation is in general due to a combination of two modes of pitching and of roll. Dickinson and Allen report conclusions from headlight research[8]. They found that, even on the smoothest level-road, the beam is continually sweeping through an arc of 3 or 4 deg., which, at a distance of 200 ft., includes nearly twice the vertical height of the car. This movement was due to hills, valleys, spring action and road irregularities.

[8] See S.A.E. Journal, August, 1932, p. 339.

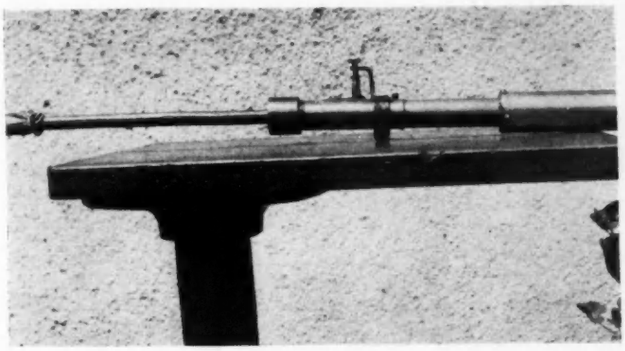


Fig. 17—Device for Applying a Known Force and Suddenly Releasing It

Measurement of Headlight Glare upon the Roadway

Continuous records of the illumination of the driver's eye from opposing cars or other lighting equipment have been obtained by W. L. Fons and D. D. Davis. The preliminary tests conducted in 1932 with a photoelectric cell, an amplifier specially designed to cover the range of illumination and an oscillograph for obtaining a photographic record, indicated that satisfactory results could be obtained. The photoelectric cell was mounted inside of the windshield of the automobile in a direct line with the driver's eyes. Thus the variation of intensity of the illumination and its frequency due to irregular road surfaces, loose headlamps and other causes, could be permanently recorded.

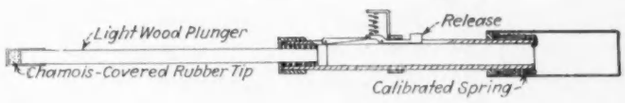


Fig. 18—Sectional View of the Device Shown in Fig. 17

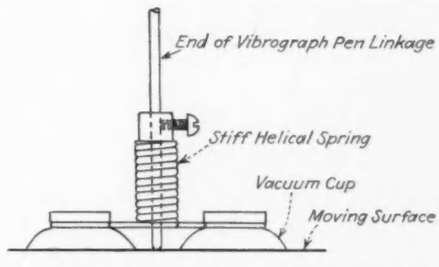


Fig. 19—Device for Attaching the Vibrograph Pen to Smooth Surfaces, Such as to the Headlamp

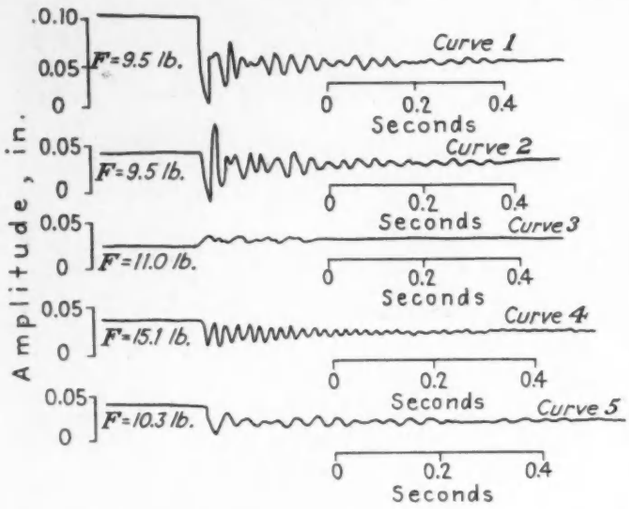


Fig. 20—Vibration of Headlamps, Modes A to E, of a 1932 Model-X Car

Curve 1, Modes B and C, vibrograph and force F both on the left headlamp. Curve 2, Modes B and C, vibrograph on the left headlamp and force F on the right headlamp. Curve 3, Mode A. Curve 4, Mode D. Curve 5, Mode E.

Amplifier and Circuit.—The circuit arrangement used is shown in Fig. 23. The photoelectric cell P is connected by a shielded cable to the vacuum-tube amplifier-unit. The plate currents of the two tubes are recorded by means of an oscillograph and a camera. An increase in photoelectric-cell current due to increased illumination causes a greater voltage drop in the coupling resistances R_1 and R_2. This in turn causes an increase in the negative-grid voltage and a decrease in the plate current of the tube T_1. At the same time the negative-grid voltage on the tube T_2 is reduced by the opposing drop in R_2, and the plate current of this tube will increase. The values of resistances R_1 and R_2, and bias voltages of the tubes, were adjusted so that tube T_1 operated on the straight portion of the characteristic curve for intensities of illumination up to approximately 0.15 ft-candle, with a sensitivity $\left(\frac{di}{dE}\right)_1$ of 75 milliamperes per ft-candle. Tube T_2 was biased so that it did not reach the straight portion of the curve until the illumination was about 0.15 ft-candle and the sensitivity $\left(\frac{di}{dE}\right)_2$ was 10.5 milliamperes per ft-candle. The circuit arrangement and adjustment make it possible to record intensity of illumination up to 2.0 ft-candles with satisfactory sensitivity for the low intensities. Curves showing the plate current as a function of illumination are shown in Fig. 24.

Oscillograph and Camera.—The oscillograph used was a six-element type of standard make fitted with an adapter for mounting a special oscillograph camera using 35-mm. film. A 6-volt motor was used to drive the film rolls. High-

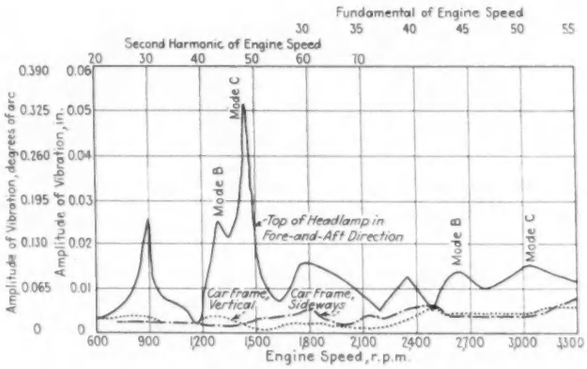


Fig. 21—Amplitude of Vibration of a Headlamp as a Function of Engine Speed for a 1928 Model-Y Car

The scales show frequency of vibration in cycles per second.

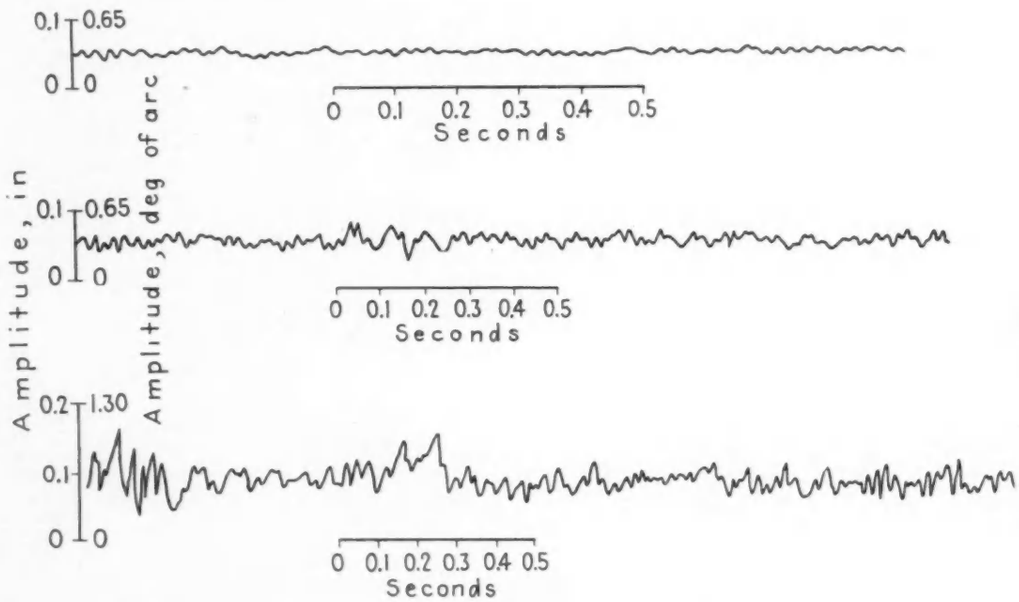


Fig. 22 — Vibrograph Records of Headlamp Vibration when Coasting Over Various Roadway Surfaces with the 1928 Model-Y Car

The upper curve represents coasting over concrete pavement; the middle, over rough road; and the lower, over very rough road.

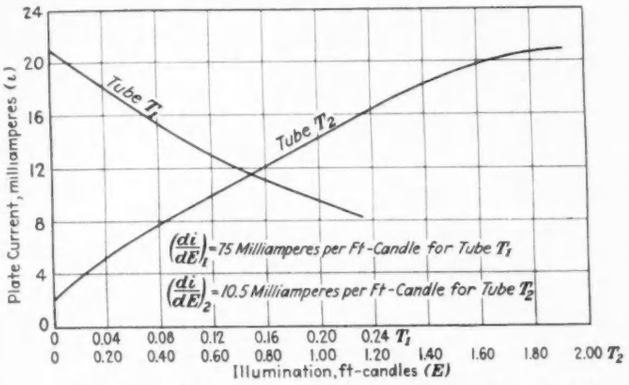


Plate Current, milliamperes (i)
Tube T_1
Tube T_2
$\left(\frac{di}{dE}\right)_1$ = 7.5 Milliamperes per Ft-Candle for Tube T_1
$\left(\frac{di}{dE}\right)_2$ = 10.5 Milliamperes per Ft-Candle for Tube T_2
Illumination, ft-candles (E)

Fig. 24—Calibration Curves of the Photoelectric-Cell Amplifier

sensitivity elements, approximately 0.006 amp. per in., were used with adjustable shunts to obtain deflections of suitable magnitude for the width of the film used.

Neon Chronometer.—To obtain a timing record of the films, a third element of the oscillograph recorded the current in a 2-watt 110-volt neon glow-lamp. The circuit shown in Fig. 23 consisted of the neon lamp in parallel with a condenser which received a charge from a 90-volt battery through a 2.5-megohm resistance. The condenser and resistance were adjusted until the period of oscillation was very nearly to 0.1 sec. The calibration was obtained by comparing the recorder of the neon chronometer and a 60-cycle voltage-wave on the same oscillogram. This calibration was checked several times later and no variation was detected.

A 4.5-volt battery in series with a 200-ohm resistance and a key, *A*, were connected in parallel with the timing element. With the key depressed, the timing record on the film was slightly displaced. The key *A* was mounted on the steering wheel and was used to indicate the instant at which glare was experienced and the time interval during which the driver experienced discomfort from glare. A second key, *B*, was connected in parallel with key *A* and was used by the observer to indicate when the cars were opposite each other so that this instant could also be identified on the film. It was found that glare was not experienced at the instant of passing, as marked by key *B*, and thus the two records were separate and distinct.

All equipment except the photoelectric cell was placed in

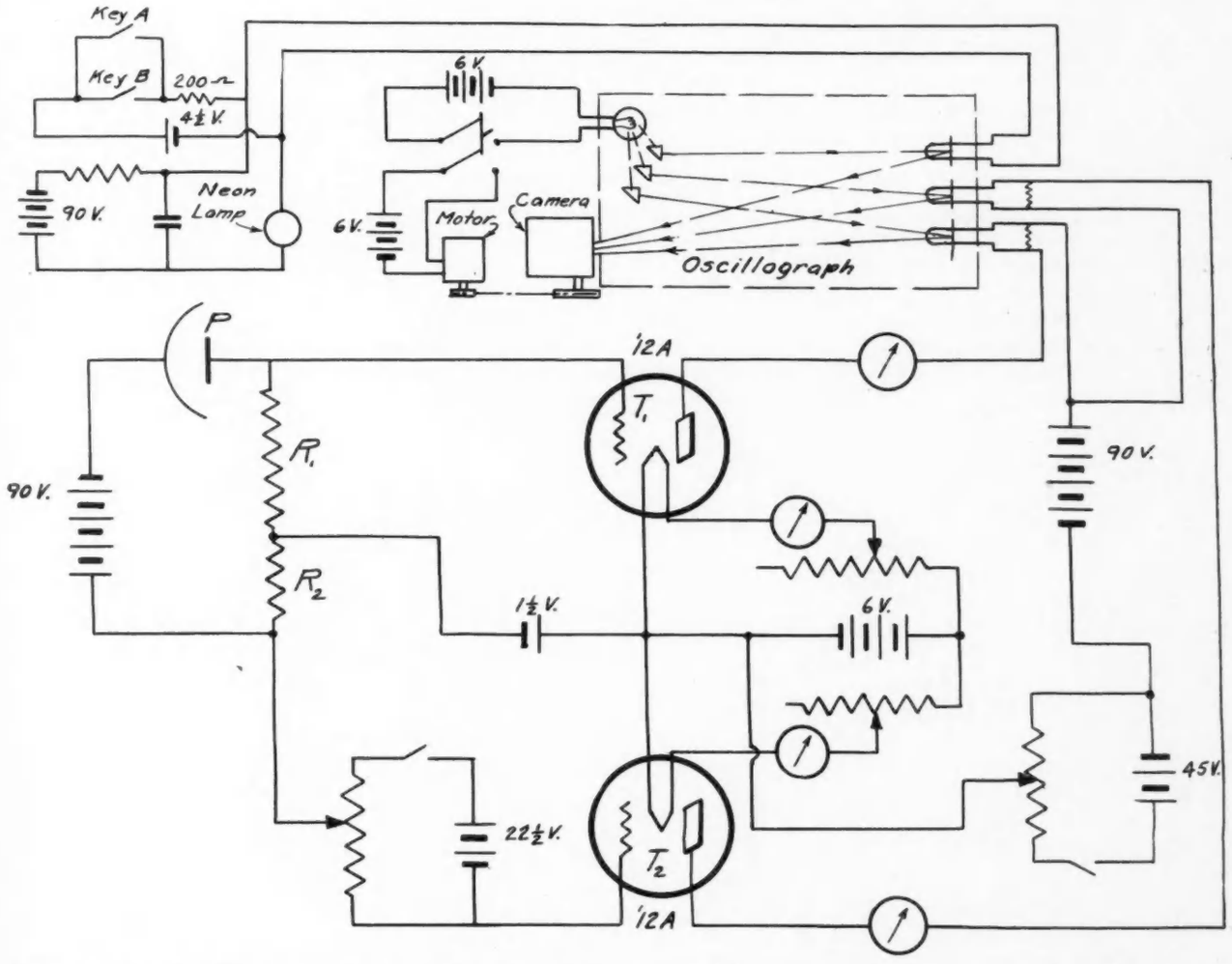


Fig. 23—Circuit Used when Measuring the Illumination from the Headlamps of Opposing Automobiles

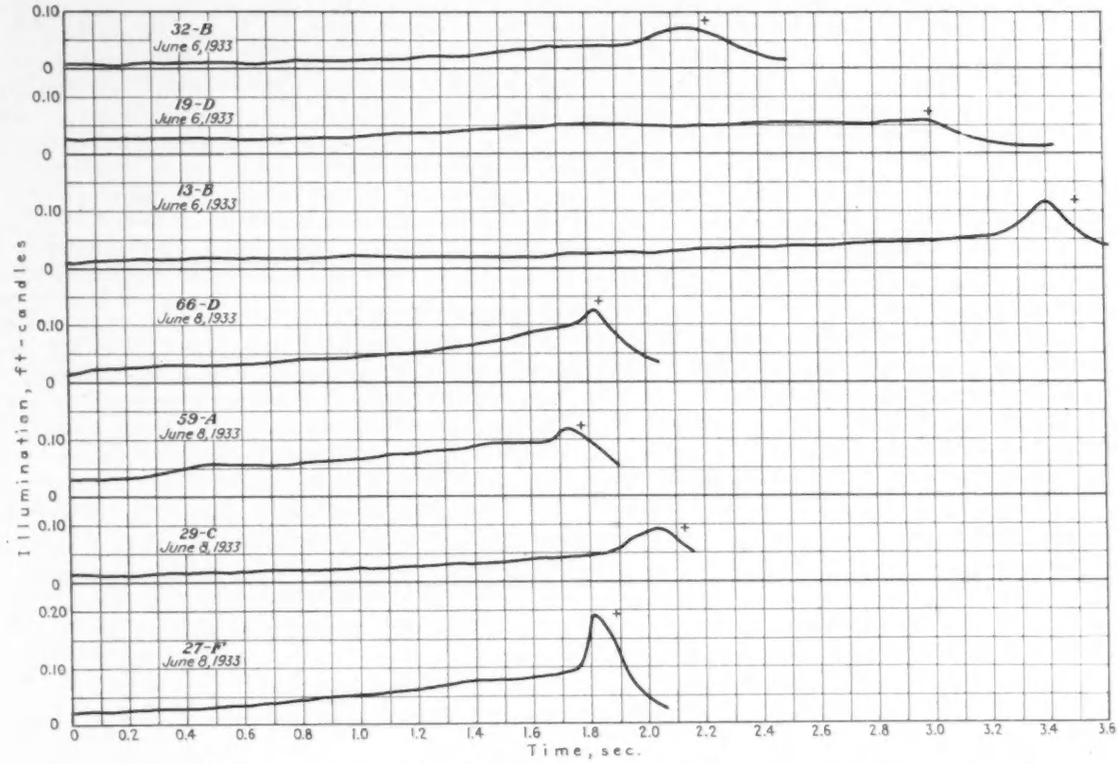


Fig. 25—Illumination at the Driver's Eyes from the Headlamps of Opposing Automobiles

The gray pavement was 20 ft. wide. The approximate relative speed was 60 m.p.h. The crosses indicate the instant of meeting.

the rear part of the automobile. The cell was mounted on the inside of the windshield above the steering wheel in the driver's line of vision. The transmissivity of the windshield was determined as 0.89.

The automobile used by the observers was equipped with Depress Beam Headlamps, of 8½ x 8 in. effective lens-diameter. S-10, 21-21 s-cp. bulbs were used, and the battery was in good condition. The lens and reflector were both kept clean and polished. The upper beam was used throughout the test and was adjusted so that the cut-off of the beam at 25 ft. was at the same height as the headlamp centers when the car was fully loaded.

Observations were carried out over a period of several weeks. It was necessary to make the test runs outside of the residential sections to obtain data of typical highway-conditions. All of the data were taken in clear weather over dry

Table 4—Correlation of Glare and Illumination Above and Below 0.07 Ft-Candle at 100 Ft. Highway Width, 20 to 25 Ft.

Make of Lens	Total Number of Cars	Number Glaring	Per Cent	Number Above 0.07 Ft-Candle	Per Cent	Number Below 0.07 Ft-Candle	Per Cent
A	30	5	17	11	37	19	67
B	24	12	50	6	25	18	75
C	42	14	33	16	38	26	62
D	43	17	40	19	44	24	56
E	4	0	0	2	50	2	50
F	60	10	17	14	23	46	77
G	1	0	0	0	0	1	100
H	27	11	41	11	37	16	63
I	8	3	38	3	38	5	62
K	6	4	67	4	67	2	33
L	3	0	0	1	33	2	67
M	7	1	14	2	29	5	71
N	1	1	100	0	0	1	100
R	5	0	0	0	0	5	100
S	3	1	33	0	0	3	100
T	1	0	0	0	0	1	100
Unknown	9	0	0	4	45	5	55
Grand Total	274	73	26.7	93	33.9	181	66.1

pavement. Most of the observations were made at a car speed of approximately 30 m.p.h.

To show the effect of various highway-conditions, approximately 750 oscillograms were taken on highways varying from 18 to 40 ft. in width and having surfaces of different types. The oscillograms obtained represent about 80 per cent of the cars passed during 300 miles of test runs. From 60 to 80 oscillograms were obtained during one evening.

Observations which yielded the instant of meeting and the period during which the light from the opposing car impaired the vision of the driver were taken. The driver looked directly ahead and did not look into the opposing headlamps. The eyes of both observers were tested by an optician and were found to be emmetropic, free of defects or astigmatism and with a visual acuity of 20/20, except for the right eye of one observer which was slightly under 20/20. Roadway conditions, car speeds, type of pavement, right turns, left turns, vibrating headlamps due to loose mounting and other permanent data, were recorded.

Partial Results of the Roadway-Glare Tests

The oscillograms thus far analyzed reveal that glare, in the opinion of the driver and the observer, is absent when the illumination at the eyes of the driver from the opposing headlamps at 100 ft. is less than 0.07 ft-candle. Table 4 indicates the results from 274 oscillograms taken on 20 to 25-ft. highways which were reasonably level and with no turns. The percentage above 0.07 ft-candle at 100 ft. is slightly greater than the percentage recorded as glaring by the driver and observer; therefore, the value 0.07 ft-candle as the average may be slightly low. Different types of pavements appeared to have no appreciable effect on the percentage of headlamps that glared.

For headlamp positions similar to conditions of meeting on a 20-ft. highway, the several oscillograms taken of the illumination at the eyes of the observer from stationary headlamps, properly adjusted, using the upper beam, showed that, at 150 ft., the illumination was usually less than 0.05 ft-candle and gradually increased as the car approached the

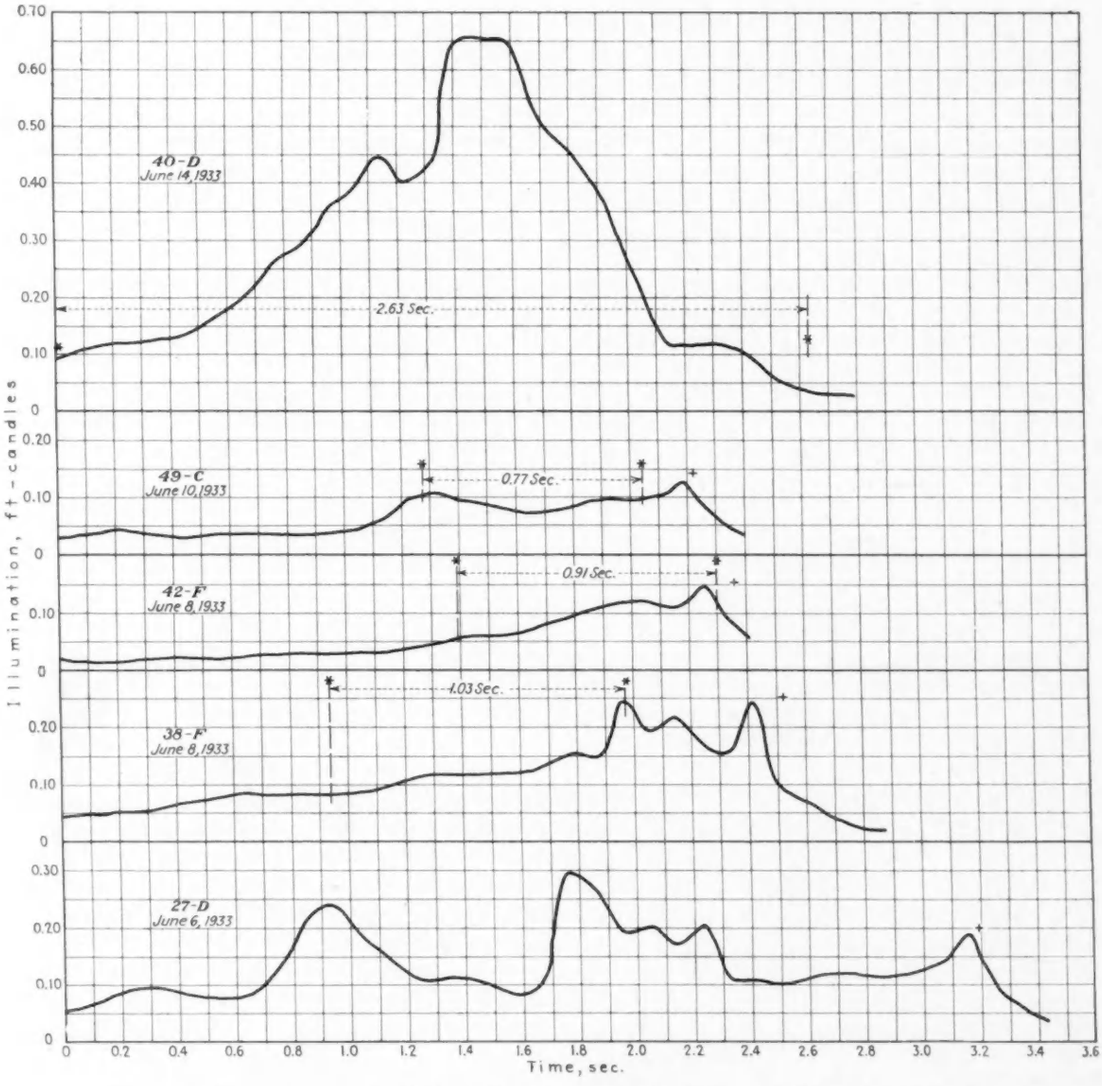


Fig. 26—Illumination at the Driver's Eyes from the Headlamps of Opposing Automobiles

The gray pavement was 20 ft. wide. The asterisks indicate the time during which vision was impaired by glare; the crosses, the instant of meeting.

stationary headlamps but did not exceed 0.07 ft-candle until the approaching car was within 50 ft. The illumination increased rapidly during the last 50 ft. to a maximum just before passing, the value seldom exceeding 0.15 ft-candle but varying with different headlamps. The high illumination experienced by the driver during the 50 ft. before meeting does not impair his vision.

The graphs in Fig. 25 are from oscillograms taken of several different types of headlamps which did not appear to glare. The number accompanying each graph indicates the oscillogram number for the particular date, and the letter indicates the type of headlamp. The cross at the end of each graph indicates the instant at which the cars were opposite each other and was recorded by the observer with the key *B* shown in Fig. 23.

The upper four graphs in Fig. 26 and the middle graph, 86-*A*, in Fig. 27, are of cars which were recorded by the driver and the observer as glaring. The time indicated between the asterisks was the interval during which the driver pressed key *A*, shown in Fig. 23, corresponding to the time that his vision was impaired due to glare.

Graph 27-*D*, Fig. 26, is an oscillogram of the illumination at the driver's eyes from the headlamps of a car while passing over a moderately rough road. The headlamps were recorded as glaring, although the driver did not record that his vision was impaired.

The graph of Car 37-*A*, Fig. 27, is typical of a few recorded in which the maximum illumination at the driver's eyes is much higher than the average. This condition probably exists when one headlamp is out of focus, causing a wide vertical spread.

[9] See *Transactions of the Illuminating Engineering Society*, vol. 14, No. 2, March 20, 1919, p. 100.

It is hoped that it will be possible to publish the complete analysis of this series of tests in the near future.

Conclusions

(1) The mechanical performance of headlamps has been improved greatly during the last several years.

(2) Laboratory tests involving durability, vibration, and dust and moisture infiltration determinations, may be used to advantage to predict roadway performance.

(3) Minimum vibration of the dynamical headlamp system due to engine excitation requires a relatively elastic system. The curves in Fig. 9 indicate that the ratio of forced to natural frequency must be high for a minimum amplitude of vibration—on the right-hand side of resonance—which, for a given engine-speed, implies a low natural frequency of the system.

(4) Road-shock excitation, however, requires a relatively rigid mounting; that is, operation on the left side of resonance as in Fig. 9, because an inert elastic system of low natural frequency which will not respond to road shocks would prove disproportionate in size.

(5) Definite trends in the natural frequencies of headlamp systems, in the various modes, are not evident. Increased rigidity has often been accompanied by increased inertia with no resulting change in the natural frequency.

(6) Abundant photometric data, supported by a limited number of psychologic subjects—two observers—indicate 0.07 ft-candle at 100 ft. as a criterion of glare. This is in substantial agreement with the results of the 1918 Pelham Parkway and White Plains tests which served as a basis for the determination of 800 a-cp. at Point 1U, 4L (Point D) as the glare limit[9].

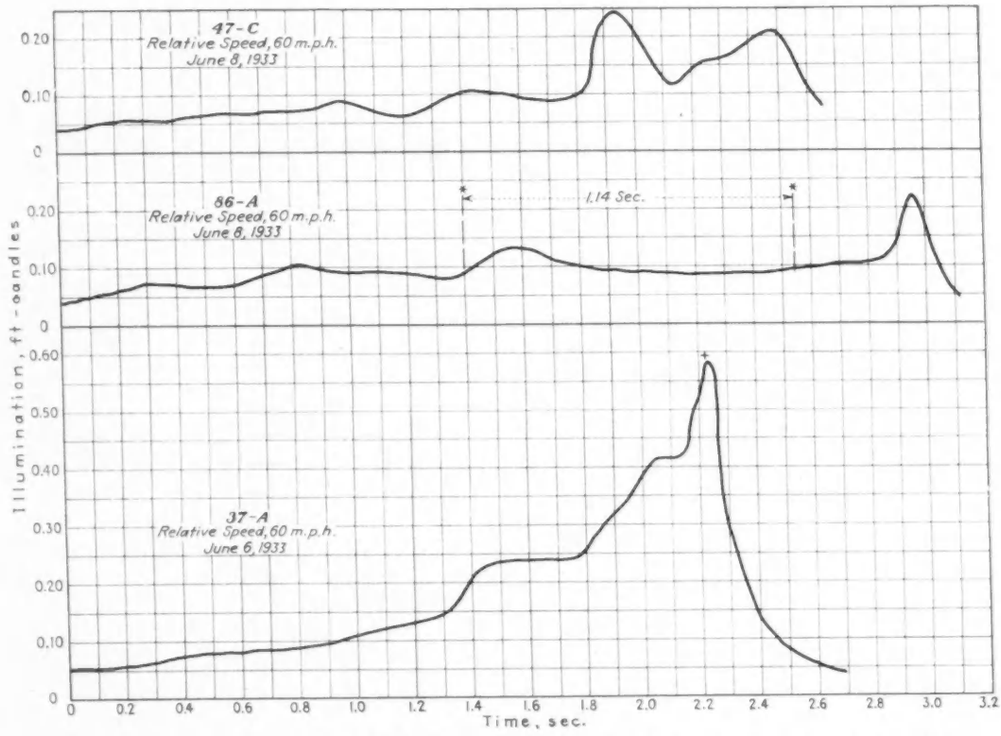


Fig. 27—Illumination at the Driver's Eyes from the Headlamps of Opposing Automobiles

The black-asphalt pavement was 20 ft. wide. The asterisks indicate the time during which vision was impaired by glare; the crosses, the instant of meeting.

Photographic Study of Combustion in Compression-Ignition Engine

By A. M. Rothrock

Associate Physicist, National Advisory Committee for Aeronautics

THIS combustion study was made in a high-speed compression-ignition engine. A high-speed motion-picture camera and an optical indicator were used to take motion pictures of the flame travel and the pressure development during combustion in the N.A.C.A. combustion apparatus. Tests were made in which both the injection-advance angle and the engine-coolant temperature were varied. The results show that, in a compression-ignition engine with a quiescent combustion-chamber, the flame first appears in the spray envelope and from there spreads to other parts of the chamber. The course of the combustion is controlled by the temperature and pressure of the air in the chamber from the time at which the fuel is injected until the time at which combustion starts.

The conclusion is presented that, in a compression-ignition engine, the ignition lag should be decreased to the largest value that can be used without excessive rate of pressure rise. Any further decrease in this lag decreases the combustion efficiency of the engine.

THE combustion processes in the high-speed compression-ignition engine are probably the least understood phenomena of all those connected with the development of this type of engine. The chief reason for this lack of understanding is that, during combustion, we have a combination of physical and chemical reactions taking place in an extremely short time-interval which cannot be stopped until they are completed. Coupled with this speed, the fact that the reactions are accompanied by extremely high pressures and temperatures makes it difficult to determine the physical and chemical laws which control the combustion process.

The experimental study of combustion can be said to have been started in the seventeenth century by Robert Boyle and his co-workers and, though these researches have been continued during the subsequent 300 years, we are still far from obtaining the complete solution of the problem. The study of combustion in the internal-combustion engine is only one phase of the general combustion-problem, and the study of combustion in the compression-ignition engine is a part of this phase. However, in studying the general researches on combustion, we can learn much that is directly applicable to our particular problem.

The introduction of photography supplied a new tool for men who were investigating combustion, for, by this means it was possible to follow the flame movement in explosive reactions, and, although the flame does not necessarily indicate either the start or the completion of the chemical reactions, the flame is a physical manifestation of certain reactions taking place in the chemical mixture and may in some cases indicate the speed of reaction.

To record photographically the flame in a compression-ignition engine it is necessary to have a transparent medium for the walls of the combustion chamber. In the spark-ignition engine, in which the combustion can always be started at a single point, the speed of flame propagation can be investigated by means of a narrow window extending across the combustion chamber, the method used by Withrow and Boyd[1], in the General Motors Laboratory. Of course, additional information can be obtained by placing in the combustion chamber numerous small glass windows so that the flame propagation can be investigated in more than one direction. This method is used at the Bureau of Standards for stroboscopic investigation of the flame[2].

Apparatus

When the National Advisory Committee for Aeronautics started its investigation of combustion in the compression-ignition engine it was decided to build a combustion chamber in which the sides were formed of single glass plates of 2.5-in. unsupported diameter so that the whole course of the flame propagation could be studied[3]. The apparatus as originally constructed consisted of a single-cylinder engine driven by an electric motor. The combustion chamber was in the

[This paper was presented at the 1934 Annual Meeting of the Society, Detroit.]

[1] See *Industrial and Engineering Chemistry*, May, 1931, p. 539; Photographic Flame Studies in the Gasoline Engine, by Lloyd Withrow and T. A. Boyd.

[2] See N.A.C.A. Report No. 399, 1931; Flame Movement and Pressure Development in an Engine Cylinder, by Charles F. Marvin and Robert D. Best.

[3] See N.A.C.A. Report No. 429, 1931; The N.A.C.A. Apparatus for Studying the Formation and Combustion of Fuel Sprays and the Results from Preliminary Tests, by A. M. Rothrock.

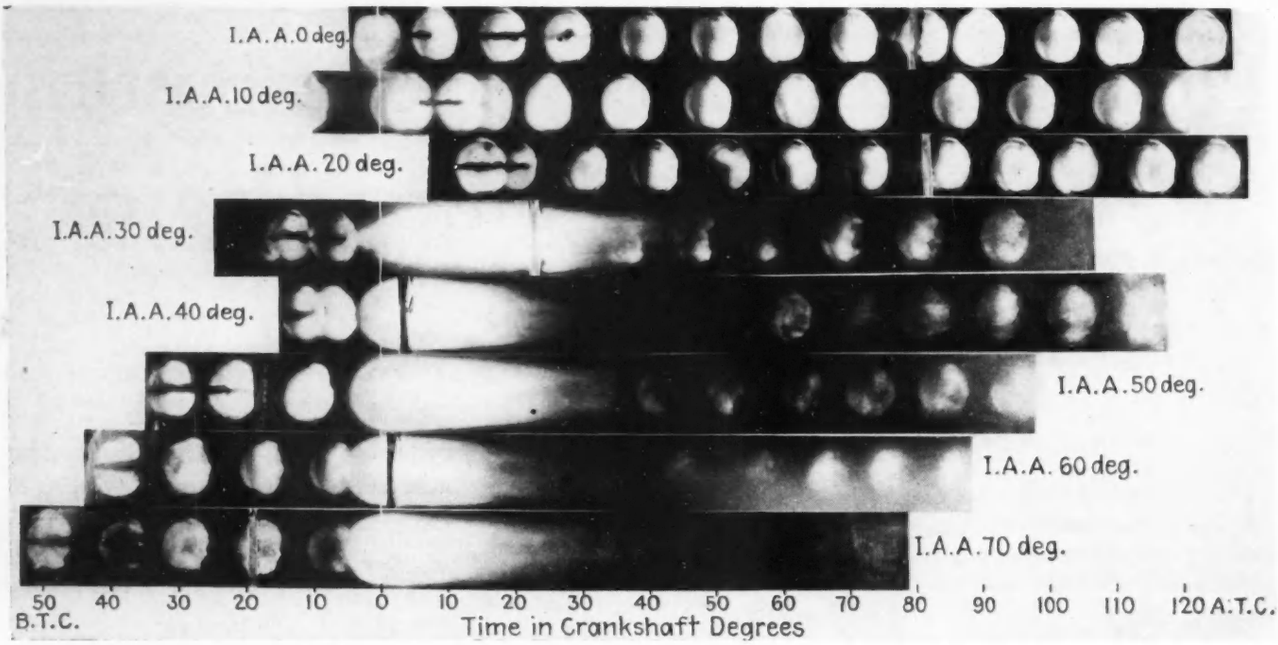


Fig. 1—Vaporization and Combustion of Fuel Oil at 250-Deg. Fahr. Engine-Temperature

The engine speed was 1500 r.p.m., the fuel quantity 0.00029 lb., and the discharge-orifice diameter 0.020 in. The abbreviations I.A.A., B.T.C. and A.T.C. mean, respectively, ignition-advance angle, before top center and after top center.

shape of a vertical disc so that two sides of the chamber could be formed by the glass windows. A single charge of fuel was injected into this combustion chamber and the spray development was photographed by the spark-discharge high-speed motion-picture apparatus developed by the N.A.C.A. for the purpose of studying fuel-spray phenomena. When combustion took place, it was recorded photographically by its own light. Since the camera had no shutter, a continuous record of the flame was obtained. Consequently, the spread of the flame in the plane of the film and normal to the direction of the film could be determined[4].

A typical series of such photographs is shown in Fig. 1. In this experiment a single 0.020-in. fuel-discharge orifice was used, discharging vertically into the combustion chamber. As the photographs show, the fuel did not ignite when it was injected between 20 deg. before and top center. With injection at 30 deg. before top center, the combustion started from around the fuel jet and spread from there throughout the chamber. With a greater injection advance, the fuel was so completely vaporized and distributed before the start of combustion that ignition apparently took place simultaneously throughout the chamber, as shown by the semicircular image formed for the start of the flame. In these latter cases the burning was accompanied by severe detonation.

In making these tests the initial charge of air in the engine cylinder was continually compressed and decompressed while the engine was being brought to speed. As a result, the air was cooled considerably at the bottom of each stroke so that the temperature at the top of the stroke was much below that occurring in an actual engine. Therefore, it was necessary to heat the engine jacket up to 250 deg. fahr.—by means of heated glycerine—before combustion such as that shown in Fig. 1 was obtained.

[4] See N.A.C.A. Report No. 435, 1932; Fuel Vaporization and Its Effects on Combustion in a High-Speed Compression-Ignition Engine, by A. M. Rothrock and C. D. Waldron.

To make the operating cycle more comparable to actual engine-operating conditions, it was necessary to provide some means for scavenging the engine on all strokes previous to that during which the fuel was injected. Normal scavenging being out of the question because of the special nature of the apparatus, an hydraulically operated valve was installed in the cylinder head. This valve remained opened except for the cycle during which injection took place. At the start of this cycle the valve was closed by hydraulic pressure and remained closed for the duration of the cycle, after which it opened for the purpose of removing the hot exhaust-gases on the following compression stroke. The immediate removal of the hot gases was necessary to prevent failure of the glass windows. With this alteration to the apparatus, the conditions of operation are quite similar to those of the actual engine.

The Apparatus Now Used

A diagrammatic sketch of the apparatus as it is now used is shown in Fig. 2. The glass windows on one side have been replaced by an optical indicator actuated by the deflection of a 2-in. diaphragm forming that side of the combustion space. Because of the large diameter of the diaphragm, the vibrations of the unit have an extremely high period and, consequently, a smooth record of the pressure changes in the chamber is obtained except in the case of severe detonation. The diaphragm motion is recorded on the film mounted on the drum by means of the light beam and the pivoted mirror. The film turns at a linear speed of 100 in. per sec.

The injection pump consists of a cam-operated plunger which compresses a charge of fuel in a small reservoir of about 1-cu. in. capacity, and a spring-operated valve which releases this fuel under pressure to the injection tube and so to the injection valve. The fuel to be tested is contained in the fuel tank, which is supplied with suitable heating and cooling coils. A primary pump forces the fuel at a pressure

of 100 lb. per sq. in. through the check valve into the pump reservoir. From here the fuel can return through the valve *B* to the fuel tank. Except for that cycle during which injection takes place, the valve *B* is held open, and the pump plunger on its up-stroke simply forces the fuel back to the tank through this valve. When the clutch is engaged, the valve *B* closes and the up-stroke of the plunger compresses the fuel in the pump reservoir. Just before the plunger reaches the top of its stroke it strikes the stem of the valve *A*, opening the valve. This action releases the pressure in the reservoir to the injection tube. As a result, an hydraulic wave is transmitted through the injection tube. When this wave reaches the injection valve, it forces up the injection-valve stem—a conventional spring-loaded valve is used—and the fuel is injected into the engine. Injection continues until the wave energy is dissipated so that the injection-valve stem again returns to its seat. After the camshaft has made one revolution, the clutch disengages so that a single injection of fuel is obtained. The quantity of fuel injected is controlled by the injection-valve opening-pressure.

Fig. 2 also shows that some of the fuel from the primary pump can, by means of the check valve, enter the injection tube without passing through the injection-pump reservoir. The fuel that follows this second path traverses the injection tube to the injection valve. Because the primary pressure is less than the injection-valve opening-pressure, the fuel cannot enter the combustion chamber. Instead, it passes through four 0.010-in. holes drilled in the injection-valve stem up through the stem, past the thermometer shown in the top of the injection valve, and so to the tube which returns this fuel to the fuel tank. The purpose of this continuously circulating fuel is to permit the temperature of the fuel in the injection valve to be controlled. The energy of the pressure wave causing the injection of the fuel is sufficient to open the injection valve even though some of it is dissipated in the four 0.010-in. holes in the stem. The check valve prohibits dissipation of the wave through the line to the primary pump.

Compression-Release-Valve Control

The compression-release valve is operated by the valves *C* and *D* and the large reservoir shown at the extreme right. The oil in the reservoir is brought up to a high pressure by means of a hand pump. The clutch is so constructed that is engages shortly before bottom center of the piston. When the piston reaches bottom center, valve *D* is opened and the oil in the reservoir is released through the tube to the compression-release valve, closing the valve. The compression-release valve is of the needle type, with the hydraulic pressure acting on the end of the stem. The valve *C* is opened 180 camshaft deg., that is, 360 crankshaft deg. after the opening of the valve *D*. When the valve *C* is opened, the pressure in the tube to the compression-release valve is released to atmospheric pressure and the cylinder pressures force open the compression-release valve.

The indicator record is timed with the engine by means of the spark gap in the indicator. This gap is connected to a high-tension coil, the primary of which is operated by a

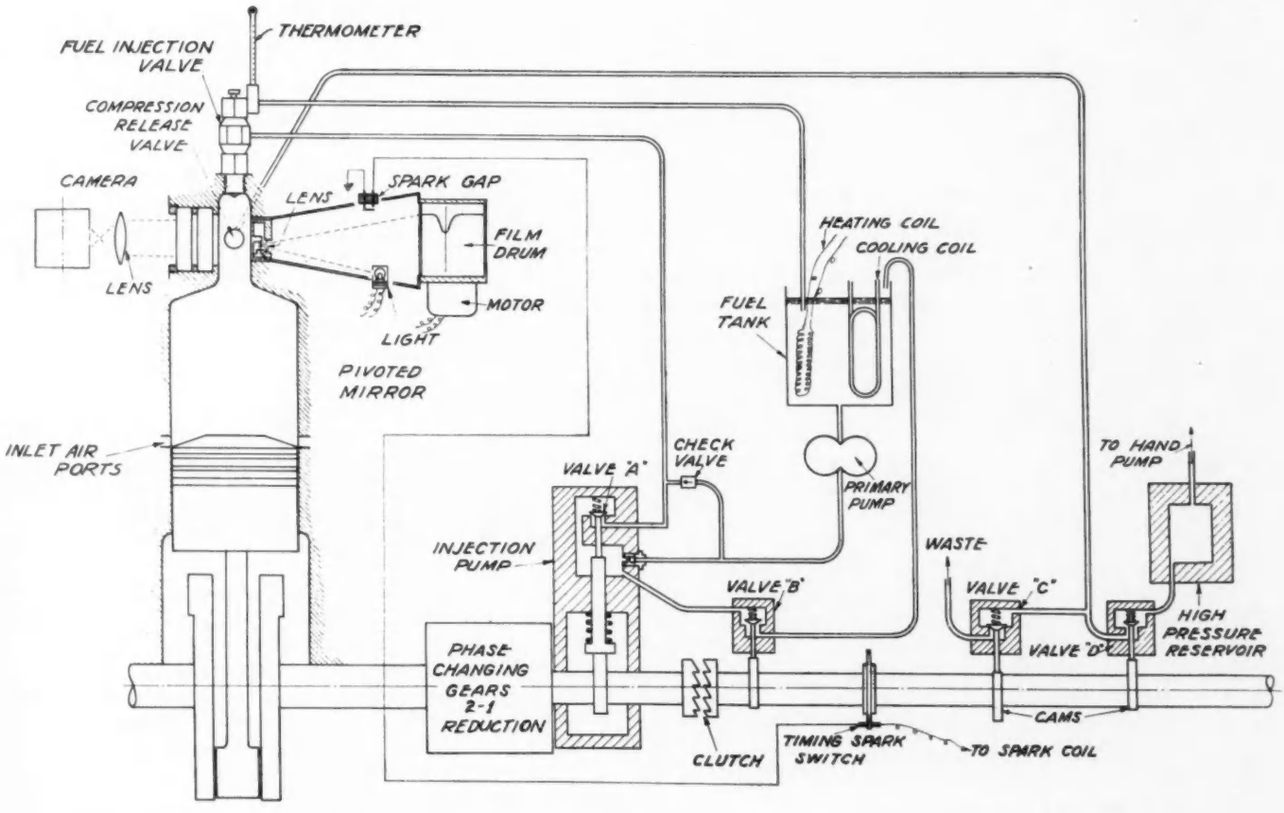


Fig. 2—Diagrammatic Sketch of the N.A.C.A. Combustion Apparatus

breaker mechanism driven from the engine crankshaft. A switch is incorporated on the camshaft of the apparatus so that the circuit is completed only on the cycle during which injection takes place. During this cycle, one line is recorded on the indicator record at top center and one at 90 deg. after top center. It is necessary to place two lines on the record because the engine is momentarily accelerated by the single explosion.

With the apparatus shown in Fig. 2, the operation is apparently quite similar to that of an actual engine. Autoignition of the fuel will take place with no auxiliary heating of the engine, and will also take place over the range of injection advance or retard angles experienced in engine testing. For the present tests, the compression ratio of the engine was 14.8. The combustion chamber was quiescent in that there was not sufficient airflow in it to affect the fuel distribution[5].

To obtain photographs of the flame propagation in two directions, it was necessary to have a camera that would not only take pictures at a high rate of speed but that would also, by means of a shutter, *stop* the flame travel long enough to obtain a pattern of the flame in the combustion chamber. Several such cameras have been developed, notably in Japan and in Germany. Unfortunately, these cameras work through a system of rotating lenses or mirrors and are consequently very expensive. Recently, a suitable camera has been developed in this country by the Electrical Research Products, Inc. This camera uses commercial 16-mm. motion-picture film. Motion pictures can be taken at rates up to 2000 frames per sec. simultaneously with a timing record that can be read to 0.001 sec. In addition, the camera can take up to 4000 frames on a single run.

It is the purpose of this report to discuss the photographic results obtained by the N.A.C.A. with this camera in conjunction with the high-speed optical-indicator. When the high-speed camera is used, an additional spark-gap in series with that used to time the indicator is focused on the motion-picture film so that the flame record is synchronized in conjunction with the indicator record. Since the motion-picture record contains an absolute time-scale, the time-scale can be accurately determined for both records.

Test Results

A series of typical records is shown in Fig. 3. This particular series was taken before the synchronization sparks were used; so, the exact timing of the flame records is not known. However, other tests have shown that the start of flame and the start of combustion-pressure rise occur fairly close together. The speed with which the photographs were taken was about 1300 frames per sec. Furthermore, in this series the flame and indicator records were taken on separate runs. (When this paper was presented, a series of motion pictures was shown in which the indicator and flame records were taken simultaneously and in which the synchronous sparks were recorded.)

In the first series of flame photographs at an injection-advance angle of 0 deg., that is, injection start at top center, the flame is seen to start around the cores of the sprays from the multi-orifice nozzle. In the second frame, the flame has spread through most of the chamber with the exception of the top (at the right in Fig. 3), but the outline of the flame around the main two orifices can still be distinguished. The exposures indicate that the start of combustion is in the fuel that formed the envelope of the spray core.

As Lee's tests[6] have shown, this envelope contains very little of the fuel. Consequently, because of the increased distance between the drops, they can be more quickly brought to the state necessary for autoignition. After the burning has started, the flame spreads to other portions of the fuel which have been prepared for combustion and so fills most of the chamber. It is particularly interesting to note that the flame in no case reaches the top of the chamber where the fuel-discharge nozzle is mounted. We can conclude, therefore, that in the time available the fuel is not distributed to this section. The probable explanation is that, because of its kinetic energy, the fuel passes through the air in this part of the chamber and the time is not sufficient for the vaporized fuel to return. In addition, the photographs indicate that most of the fuel, that is, the fuel in the core of the spray, must penetrate through the burning envelope to the fresh air outside the envelope. The necessity for completing the mixing after combustion is started tends to lower the combustion efficiency of the engine as has been shown in an earlier report[7].

"After-Burning" Period

After the flame has reached most of the air in the chamber, the period of "after-burning" starts and the flame gradually disappears. Although the flame propagation during the initial burning is quite reproducible, this after-burning period is only reproducible in that there seems to be no general pattern for the disappearance of the flame. The photographs show that the flame fades away into small isolated sections and that these sections persist for quite a time, finally disappearing entirely.

When the second series of flame photographs with an injection start of top center was taken, the spark-discharge system was used, the reflector was mounted opposite the camera and glass windows were installed on both sides of the combustion chamber. The sparks were then timed so that they took place during the injection of the greater part of the fuel, but stopped before the start of inflammation. Consequently, first a silhouette of the spray was obtained—see the first two frames—and then photographs of the combustion. This method of taking photographs of both the spray and the flame has not as yet been perfected; so, very few of these pictures have been obtained. The spray from the two main orifices can be seen in the second frame to have penetrated across the combustion chamber. Two of the auxiliary sprays on the outside of the main sprays can also be seen in the enlargements shown in Fig. 4.

In the next frame, in Fig. 3, the flame is around the position of the two main sprays. Measurements show the exact location to be in the envelope between the sprays. In the following photograph the flame has spread to include all the sprays and in the next exposure the spray outline is lost as the flame fills most of the chamber except that part close to the injection-valve nozzle. The burning is then similar to that discussed for the previous series until the after-burning period is well under way. The after-period is now characterized by numerous small "spheres" of incandescence. Just what they represent is difficult to say at present. The first conclusion is that they are liquid drops of unburned fuel that are now burning. The explanation is not so plausible when it is considered that this theory requires that these drops re-

[5] See N.A.C.A. Technical Note No. 430, 1932; Effects of Engine Operating Conditions on the Vaporization of Safety Fuels, by A. M. Rothrock and C. D. Waldron.
[6] See N.A.C.A. Report No. 438, 1932; Experiments on the Distribution of Fuel in Fuel Sprays, by Dana W. Lee.
[7] See N.A.C.A. Report No. 438, 1931; Combustion in a High-Speed Compression-Ignition Engine, by A. M. Rothrock.

main in the liquid state during all the period of incandescence when the gases in the chamber are probably around temperatures of 3000 deg. fahr. Further tests are being conducted to investigate this phenomenon. Examination of the locations of these spheres of incandescence shows very little motion on their part. This result leads to the conclusion that the apparent motion of the gases in the previous exposures is chiefly the motion of the flame in a nearly stationary gaseous medium. If this idea is true, it precludes the theory that the violence of the burning assists the mixing of the fuel and the air.

The optical-indicator card taken under the same conditions as the previously mentioned flame records appears quite normal. The first vertical line to the right indicates top center and the second line indicates the point at which the explosion pressure breaks away from the expansion line. To the extreme left can be seen the second line indicating the position of 90 deg. after top center. The engine speed in this and the subsequent tests, the results of which are shown in Fig. 3, was 570 r.p.m.

With an injection start of 20 deg. before top center, as in Fig. 3, the flame start is seen to occur in two places, apparently in the spray envelope between the two main sprays and in the envelope between one of the main and one of the auxiliary sprays. The flame propagation is more rapid than in the previous photographs, as is shown by the second frame in which the flame fills most of the chamber. There appears to be little change in the flame for the next nine frames. In the tenth frame, the flame starts to disappear in the bottom of the chamber and, from then on, the flame gradually fades away throughout the chamber. These photographs do not show the spheres of incandescence that appeared with the injection start at top center. In fact, the results taken to date have shown that these spheres are most apt to appear with either an extremely long ignition-lag or a very short lag. The indicator card for an injection start of 20 deg. before top center shows that the rate of pressure rise was fairly rapid, but not objectionably so. The first line to the right indicates the break-away point and the second line, top center.

When the injection-advance angle was increased to 40 deg. before top center, as in Fig. 3, the combustion took place with severe detonation. No flame start is apparent until practically the whole chamber is flaming. In another series of exposures under the same conditions, the start of flame was recorded but, instead of being near the core of the spray positions, the start was in the lower part of the chamber. The period of incandescence of the most of the chamber is much shorter now than it was with either of the later injection-advance angles and the flame disappears more evenly and more quickly. The indicator card shows an extremely high rate of pressure rise followed by a rapid loss in pressure even before the piston had started on its down stroke. As has also

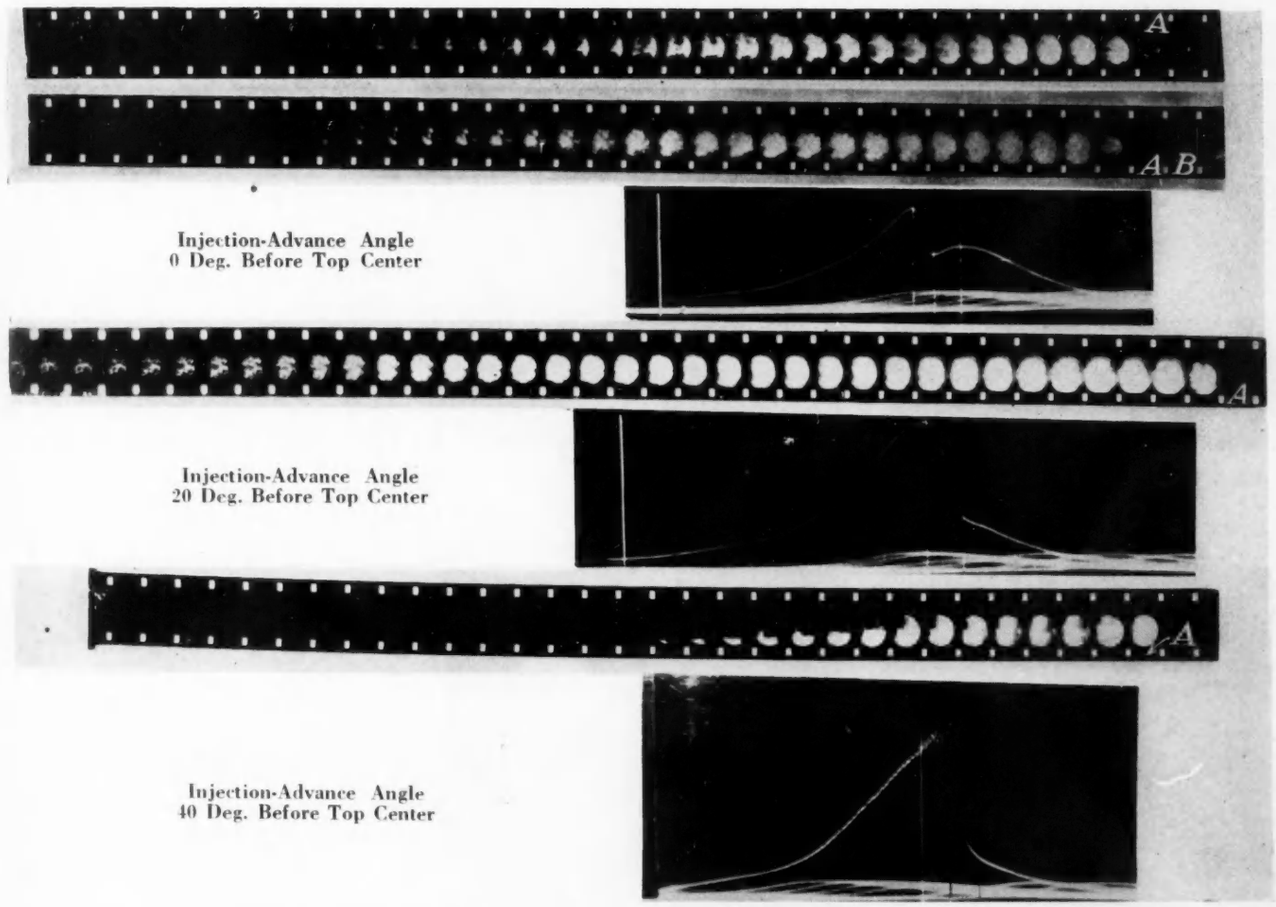


Fig. 3—Effect of Injection-Advance Angle on Flame Propagation and Pressure Rise in a Compression-Ignition Engine

The letter *A* indicates the start of the flame; the letter *B*, the fuel spray. The engine-coolant temperature was 150 deg. fahr. and the engine speed, 570 r.p.m.

been shown in earlier tests[8], this condition which permits detonation also permits greater time for the mixing of the fuel and air and therefore is accompanied both by a higher combustion efficiency and a higher rate of pressure rise, the latter of course being a prohibitive value for actual engine operation.

Fig. 5 shows some of the effects of injection-advance angle on the time of start of pressure rise caused by combustion for different jacket temperatures. For very early injection-starts, the curves tend to become horizontal and a change of 40 deg. in the injection-start shows little change in the combustion start. In addition, for late injections—and in each case the latest injection at which ignition would occur was used—the start of combustion in crank degrees after top center appears to be close to the earliest position in crank degrees before top center at which combustion would start on the compression stroke. This fact leads to the theory that in the engine there is a minimum pressure at each temperature at which autoignition can take place, and that this pressure is apparently little affected by the temperature and pressure of the air in which the fuel is injected or to which the fuel is subjected during the lag period. The curves also show that with long ignition-lags the magnitude of the engine-jacket-temperature effect is much greater than is the case with the shorter ignition-lags. Nevertheless, in each case, increasing the jacket temperature decreased the ignition lag; also, the latest injection at which ignition occurred increased considerably with the increase in engine-jacket temperature. It can be concluded that, for engine operation in which long ignition-lags do occur, they can be shortened by a reasonable increase in the jacket temperature; but, in those cases in which the ignition lag is short, increase in the jacket temperature will not have much effect.

Fig. 6 shows the effect of injection start and jacket temperature on the ratio of the maximum explosion pressure to the normal expansion or compression pressure. These curves are extremely interesting and show what is believed to be an important conclusion. The ratio of the explosion pressure to the normal expansion or compression pressure is not a direct measure of the amount of fuel burned, that is, the combustion efficiency, for two reasons. First, the ratio does not consider the fuel that is consumed in the after-burning period. Second, even though combustion is complete, the ratio is a function of the temperature at the start of combustion. As the temperature at the start of combustion is increased, the value of the ratio decreases. For instance, if the initial temperature is 100 deg. fahr., the ratio of pressures for complete combustion is approximately 4, while, if the initial temperature is 200 deg. fahr., the ratio is approximately 9. For the range of temperatures experienced in these tests, the ratio should vary between about 6 and 4.

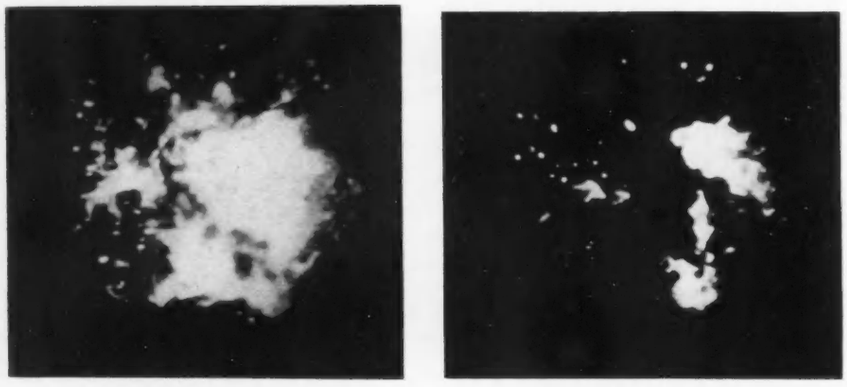
Fig. 6 also shows that, for the very early injection-advance angles and low jacket-temperature, the combustion efficiency was low and that, as the injection-advance angle was decreased, the combustion reached a maximum and then decreased to a minimum followed by a sharp increase for in-

[8] See N.A.C.A. Report No. 438, 1931; Combustion in a High-Speed Compression-Ignition Engine, by A. M. Rothrock.

Second Frame
Silhouette of the spray

Third Frame
Start of the flame

Fourth Frame
Note the two main sprays illuminated by combustion



Twentieth Frame
"After-burning"

Twenty-Fifth Frame
Continuation of "after-burning"

Fig. 4—Enlargements of Frames from the Second Series of Photographs Shown in Fig. 3

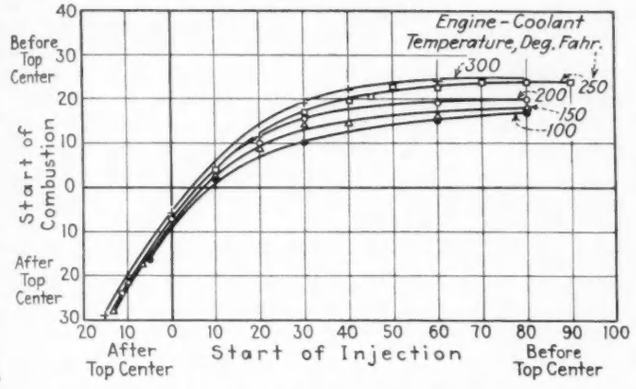


Fig. 5—Effect of Injection-Advance Angle on the Ignition Point

The compression ratio was 14.8; the engine speed, 570 r.p.m.; the displacement volume, 137 cu. in.; the fuel quantity, 0.00025 lb.; and the combustion chamber was quiescent.

jection at or after top center. With a jacket temperature of 300 deg. fahr., the pressure ratio remained almost constant over a range of injection starts of from 80 deg. to 30 deg. before top center and then dropped slightly, followed by a sharp rise. In each case where detonation occurred, it came at the first maximum value of the ratio. With the highest jacket-temperature, the engine did not detonate regardless of the injection-advance angle. This decreased rate of burning can be attributed only in part to the decreased ignition-lag as shown in Fig. 5.

With the very early injection-advance angles, the lag was great enough in every case to permit detonation had the mixture been correct. The conclusion is drawn that the course of the combustion in the compression-ignition engine is a function of the fuel distribution at the time of ignition and also of both the time interval elapsing between injection and ignition and the temperatures and pressures persisting in the combustion chamber during this time interval. Furthermore, any one of these three factors may dominate the course of the combustion. In addition, it is concluded that, with a quiescent combustion-chamber, the ignition lag of the fuel should not be decreased beyond that value which gives smooth running of the engine; for, any further decrease of the ignition lag results in a poorer mixture of air and fuel at the time combustion is started and, as a result, causes a decrease in the efficiency of the combustion. This last conclusion is important because it implies that the ignition lag of the fuels now in use is sufficiently short and that the problem of high combustion-efficiency must be attacked from the physical standpoint of distribution, although the chemistry of the fuel must not be forgotten. The cause of the sharp rise of the curves for combustion starting after top center is not known. At present it must be attributed to chemical and physical reactions caused by the adiabatic expansion of the gases before and during the combustion process, and to the decrease in the thermal losses because of the lower gas-temperatures.

Further effects of the temperature on the course of the combustion are shown in Fig. 7. The rates of heat input to the gases in the combustion chamber were derived by the method referred to in Footnote[9]. The curves show that, when the jacket temperature was increased from 150 to 300 deg. fahr., the ignition lag with an injection start of 10 deg. before top center was decreased by about 2 deg. and, for an injection start of 20 deg. before top center, by about 3 deg. However, the course of the combustion, as shown by the rate of heat-input curves and by the pressure curves, shows considerable difference for the two temperatures. The maximum rate of burning, and, as a result, the maximum rate of pressure rise, was decreased appreciably by increasing the jacket temperature. The combustion efficiency, as indicated by the area under the rate curves, was decreased. Increasing the engine temperature in turn increases the air temperature throughout the compression stroke. Consequently, the fuel was sprayed into hotter air at the higher jacket-temperature.

It had been hoped that this increased temperature would increase the rate of diffusion of the fuel vapors and so result in better mixing of the fuel and air. This result probably did occur, but it was more than offset by the disadvantage of the decreased ignition-lag and decreased air-charge. Any fuel that is not mixed with the air when combustion starts has a more difficult time in reaching the oxygen necessary for its combustion, because the fuel that has already burned has diluted the oxygen with inert gases and also decreased the oxygen content of the mixture. Fig. 7 again emphasizes the fact that, in a quiescent combustion-chamber, a short ignition-lag is beneficial from the standpoint of low rates of pressure rise but detrimental from the standpoint of combustion efficiency.

Conclusions

The following conclusions are presented:

(1) With a short ignition-lag in a quiescent combustion-chamber the burning starts from around the spray envelope and from there spreads throughout the combustion chamber. With a long ignition-lag the burning may start at any point in the chamber. In either case, the burning may start at one or more than one point.

(2) The course of the combustion, aside from the original chemical properties of the fuel, is controlled by the

(*a*) Time interval between injection and the start of combustion

(*b*) Temperatures and pressures existing in the combustion chamber during this time interval

(*c*) Temperature and pressure at the start of combustion

(*d*) Distribution of the fuel at the start of combustion

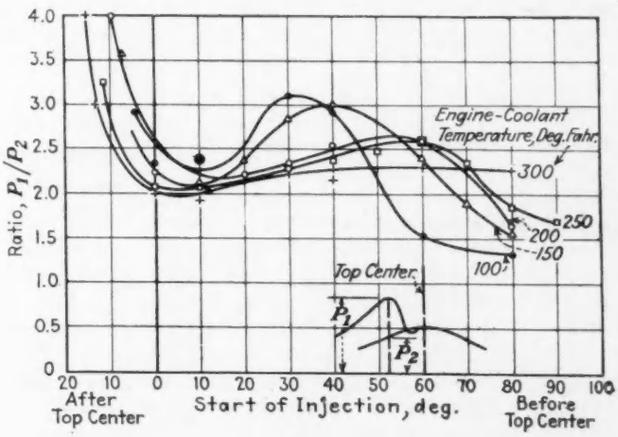


Fig. 6—Effect of Injection-Advance Angle on the Ratio of Explosion Pressure P_1 to Normal Compression or Expansion Pressure P_2

The compression ratio was 14.8; the engine speed, 570 r.p.m.; the displacement volume, 137 cu. in.; the fuel quantity, 0.00025 lb.; and the combustion chamber was quiescent.

[9] See N.A.C.A. Report No. 438, 1931: Combustion in a High-Speed Compression-Ignition Engine, by A. M. Rothrock.

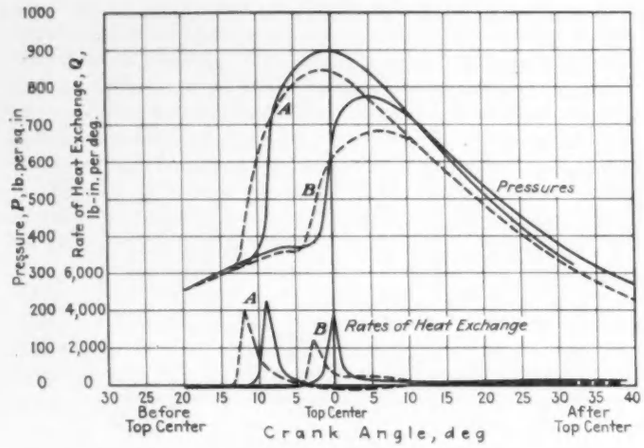


Fig. 7—Effect of Jacket Temperature on Instantaneous Cylinder-Pressures and Rates of Heat Exchange

The jacket temperature for the full-line curves was 150 deg. and that for the dash-line curves 300 deg. fahr. The letter *A* indicates injection start at 20 deg. before top center; the letter *B*, injection start at 10 deg. before top center.

The compression ratio was 14.8; the engine speed, 570 r.p.m.; the displacement volume, 137 cu. in.; and the fuel quantity, 0.00025 lb.

(3) The ignition lag in an engine with a quiescent combustion-chamber should be decreased to the value required to prevent objectionable rates of pressure rise. The ignition lag should not be decreased to less than this value because, by doing so, the combustion efficiency of the engine is decreased.

(4) In case the ignition lag in the engine is too long, it may be shortened considerably by increasing the temperature of the engine coolant.

(5) If the ignition lag of the engine is short, increasing the temperature of the engine coolant decreases the ignition lag sufficiently to decrease the rate of pressure rise and the combustion efficiency of the engine. Consequently, if the rate of pressure rise in the engine is not excessive, increasing the coolant temperature does not present any advantages.

Discussion

Curve Interpretation Discussed Constructively

—**Dr. P. H. Schweitzer**
Pennsylvania State College

MR. ROTHROCK'S investigation aims at the clearing up of some of the most important problems of internal combustion. The line of attack is well chosen and carefully prepared, but the results presented represent the beginning at best of what should be possible to obtain with such an experimental set-up. The author should be complimented for having devised the clever apparatus which simulates so closely engine conditions and yet permits the use of such indicating and recording instruments that would be impossible to mount on a real engine of small dimensions.

Referring to Fig. 5, the author's conclusions would have been clearer to the reader if he had chosen to plot ignition lags against start of injection in degrees of crank angles. That would have also confirmed an earlier observation of mine that, if combustion starts at top center, ignition lag is very close to its minimum.

An important conclusion of the paper is that "with a quiescent combustion-chamber, the ignition lag of the fuel should not be decreased beyond that value which gives smooth running of the engine; for, any further decrease of the ignition lag . . . causes a decrease in the efficiency of the combustion." It is admitted that this "implies that the ignition lag of the fuels now in use is sufficiently short . . .," as stated in the third paragraph preceding the paper's "conclusions."

While the conclusion quoted is not absurd, it is improbable, and the evidence offered is far from being conclusive, in my opinion. Referring to Fig. 6, after explaining why the P_1/P_2 ratio is *not* a measure of combustion efficiency, the author goes on with his analysis using the P_1/P_2 ratio as if it were a measure of the combustion efficiency. Then he wonders why the curves rise sharply if the combustion starts after top center. But he refuses to draw the same conclusion regarding late injection (between 0 and 10 deg. after top center) as he did regarding early injection (between 20 and 30 deg. before top center), namely, that increase in ignition lag coincides with increased combustion efficiency.

My interpretation of the curves in Fig. 6 is rather simple. The P_1/P_2 ratio is more a measure of the "explosiveness" of the combustion than of the efficiency of the combustion. An "explosive" combustion is one which approximates constant-volume combustion. The more the amount of fuel accumulated in the cylinder before ignition, the more explosive the combustion is. The fuel accumulation occurs during the ignition-lag period. It should not cause surprise, therefore, that the injection timing for minimum ignition-lag (about 10 deg. from Fig. 5) should coincide with minimum explosiveness and minimum P_1/P_2 ratios in Fig. 6. Both earlier and later timing causes a higher P_1/P_2 ratio because of the longer period of fuel accumulation before ignition. But I would not interpret this as if the "combustion efficiency" had grown with lengthening the ignition lag.

As further evidence to prove that short ignition-lag is detrimental from the standpoint of combustion efficiency, the author points out that the areas under the curves of heat exchange are large with higher jacket-temperatures; but an inspection of the curves shown in Fig. 7 fails to show that.

It is, of course, reasonable to expect that a long ignition-lag coupled with sufficiently early timing will increase the cycle efficiency[10], but it is not likely that it should increase the combustion efficiency[10] of the engine. The latter would mean that the more of the fuel there is injected into flame, the less of it burns. We know, however, that well-built slow-speed quiescent combustion-chamber engines of 100 to 150 r.p.m. have comparatively short ignition-lags—one-third to one-half of the total injection period—and still show combustion efficiencies of 80 to 90 per cent. We know, furthermore, that these combustion efficiencies do not drop when the load is raised between half load and full load, in spite of the fact that at the higher loads the comparative length of the ignition lag is reduced and a greater portion of the fuel is introduced into flame. If a short ignition-lag should be detrimental to the combustion efficiency, this fact first should have manifested itself with the old slow-speed engines, where the ignition lag is relatively short.

It is not held that, in a specific engine, the vagaries of combustion may not cause an accidental shortage of oxygen such

[10] See N.A.C.A. Report No. 401, by A. M. Rothrock, for definitions of cycle efficiency and combustion efficiency.

as the author has described in the latter part of the paragraph immediately preceding his conclusions, but I am not inclined to accept that as a description of the typical case.

I am of the opinion that a short ignition-period is beneficial to the engine from every angle. I wish to add, however, that a shorter ignition-lag may not only permit but, for best results, require a shorter injection-period. This practically means larger orifice-diameters. It is not fair to a short-ignition-lag fuel to be compared with a long-ignition-lag fuel on the basis of equal injection-setting in an engine which has injection-orifice diameters fitted for the long-ignition-lag fuel.

Inflammation, Infra-Red Radiation and Incandescence

—Charles F. Marvin, Jr.
Bureau of Standards

FOR both spark-ignition and compression-ignition engines, the desirable type of burning seems to involve a fairly rapid but progressive inflammation of the charge by the spread of flame from one or more points of ignition. This is in contrast with the objectionable type which is characterized by practically simultaneous inflammation of a considerable portion of the charge. The distinction between progressive and simultaneous inflammation, taken alone, involves merely the amount of charge ignited in a given time and the dependent rate of pressure rise, but does not necessarily presuppose any difference in the nature of the reactions during burning. However, Mr. Rothrock's observation that the period of incandescence for the burning charge is much shorter under detonating than under normal conditions appears to be evidence of a second distinction between the two types of combustion, involving not the rates of inflammation but the types or rates of the reactions following inflammation.

A shorter period of incandescence for the charge involved in fuel knock is seen also in some, but not all, of the photographs of flame travel in a spark-ignition engine published by investigators at the General Motors Research Laboratories[11]. These investigators also present spectroscopic evidence of a difference in the nature of the reactions for normal and knocking combustion.

Measurements recently made at the Bureau of Standards of the infra-red radiation from explosions in a spark-ignition engine show a more rapid rise, a higher peak and a more rapid decline in the radiation for knocking as compared to normal combustion. Since the infra-red radiation is emitted almost exclusively by water vapor and carbon dioxide, the inference is that combustion is completed sooner after inflammation in the knocking type of burning. Thus, there is some evidence that the course of knocking combustion may involve not only a more rapid inflammation but a different series of reactions which produce the final products H_2O and CO_2 more quickly after inflammation than in the normal type of burning.

Mr. Rothrock's description of the numerous small "spheres" of incandescence which sometimes appear late in the period of after-burning and are apparently suspended almost motionless in the charge applies very closely to a phenomenon observed in high-speed motion-pictures taken at the Bureau of Standards. These pictures show the spread of flame through an explosive mixture of carbon monoxide and oxygen inclosed in a soap bubble and ignited at the center. The only explanation which has been found for the "spheres" in the Bureau's pictures is that they are caused by the burning of combustible materials (principally glycerine) in stray droplets of the broken soap film.

[11] See *Industrial and Engineering Chemistry*, vol. 23, p. 539 and p. 769; vol. 24, p. 528; and vol. 25, p. 923 and p. 1359.

An Engine's Evolution

AN important element in the picture of improved motor-vehicle performance comes in the form of the higher engine speeds that are now possible with advanced design. A dramatic example for this may be had by comparing the actual performance improvement of a given engine of 250 cu. in. displacement through a period of evolution from 1930 to 1934. In 1930, this engine developed around 76 hp. and 175 ft-lb. of torque; it would withstand a 50-hr. test at wide open throttle at 3500 or 3800 r.p.m. Through the application of various improvements in design, this 250 cu. in. engine has been brought to 110-112 hp. at 195 ft-lb. of torque; it now peaks at 3800 r.p.m. and can run wide open at 4500 to 4800 r.p.m. for 100 hr. without failure.

Several important items have contributed to this improvement. First, comes the increase in compression pressure mentioned above.

Second, a study of the valve gear has helped to a great degree. Better cam design, proper selection of valve material and the elimination of valve spring surge are responsible for better performance. Carbon steel from Sweden has replaced the alloys in the valves and unusually large stems help to carry the heat away. Two methods of breaking up synchronous periods of valve springs have found extensive use; one being the application of valve spring dampers or clips which rest lightly on the spring coils and damp out the surge, whereas the second method depends upon springs designed with varying pitch to kill the surge. The familiar valve spring damper functions like a mute on a violin.

A third item that makes higher speeds and performance possible from a given displacement is the improvement in bearings. A connecting rod bearing that formerly received a unit loading of 2000 lb. per sq. in. now has to withstand 2600-2800 lb. per sq. in. How have bearings been designed to carry such loads, thus making increased performance possible? Better oil distribution to the bearings is one contributing factor, and the adoption of lead-bronze in place of babbitt is another.

Fourth in the list of improved power contributors comes better carburetion and distribution of fuel mixtures to the cylinders. With the downdraft carburetor it is generally possible to obtain higher volumetric efficiency and, thus, more power, by bringing a cooler mixture to the cylinders. Difficulties with starting have been largely eliminated by the adoption of the automatic choke, "a remarkable mouse-trap gadget" that does a wonderful job.

The amazing increase in performance has been contingent upon the parallel development of better cooling, both in the block and by the use of more generous and efficient radiator cores.

While engine power has increased, car weights have been held down or decreased. Thus, the present less-than-$1000 car can be counted upon to do 80 m.p.h.

—Abstracted from a paper presented by D. G. Roos, president of the Society and chief engineer, Studebaker Corp., to the Denver S.A.E. Club, Northern California, Southern California, Oregon and Northwest Sections, May, 1934.

Modern Headlighting Requirements

By R. N. Falge
Research Engineer, Guide Lamp Corp.

THE prospects for substantially improved headlighting conditions in the future look very promising, Mr. Falge concludes.

Assurance of safe headlighting conditions on our roads at night involves the full cooperation of those who build the lamps, those who specify how they shall be used, those who are responsible for their maintenance, and those who use them.

The automotive industry, interested technical societies and state enforcement officials have done an excellent job in establishing the fundamental requirements underlying safe headlighting and in developing test specifications to cover them.

More than three-quarters of the cars on the road are equipped with headlamps capable of complying with these requirements when properly maintained, adjusted, and used.

The stage is all set for the final drive to permit and induce motorists to adjust and use their headlamps in accordance with this practice.

Legislation is needed to specify the multiple-beam practice in all states. The National Conference on Street and Highway Safety is considering the revision of the Uniform Vehicle Code to legalize this practice at its next meeting in May.

Educational work, supplemented by active enforcement, is needed to encourage motorists to maintain their head-lamps in efficient operating condition and to use the proper beam at the right time. The National Safety Council has agreed to cooperate in putting on an intensive educational campaign.

THE automotive industry has been cooperating actively with state enforcement agencies and interested technical societies for some years in the development and promotion of a constructive program designed to result eventually in substantial and lasting improvement in headlighting conditions throughout the country.

The groundwork may be considered now as fairly well established. The fundamental requirements for safe headlighting have been determined. Most of the cars on the road have been equipped with head-lamps capable of meeting these requirements. Deficiencies in the service set-up are known and steps are under way to correct them. The trend in legislative and administrative circles is toward these more modern adjustment and operating practices. The cooperation of the driving public is reasonably assured. The time has come when a concerted drive to encourage proper adjustment and usage in service may be expected to produce results.

The Headlighting Problem

Broadly stated, the headlighting problem consists in arranging and operating head-lamps in such manner as to show up obstacles and turns at a safe distance. A popular misconception, which has been responsible for much of the confusion in this field, is that the function of head-lamps, as above stated, is secondary and that the major problem is to avoid glare to others. This misconception must be corrected before we can hope to make real progress in the headlighting field. Actually, glare, like inefficient head-lamps, improperly adjusted head-lamps, dirty windshields, defective eyesight and similar considerations, is merely one of the factors which interfere with vision of objects ahead.

Requirements for Open Road Driving

Situations are quite usual in actual practice where a visibility distance of at least 500 ft. is needed to insure safety. Considerations involved are permissible legal speeds, braking efficiency, road adhesion, down-grades and driver-reaction time. Operating conditions are such that it is not unusual to require at least 50,000 cp. to show up obstacles and turns at a distance of 500 ft. ahead, as evidenced by the results of an extensive study conducted by the General Motors Research Laboratories and summarized in Table 1.

From these figures it will be noted that under ideal con-

[This paper was presented at the Annual Meeting of the Society in Detroit, January, 1934.]

ditions—a driver with normal eyesight looking through a clean windshield on a clear, dry night with no opposing head-lamps—about 25,000 cp. is needed to reveal a dark-colored object 1 ft. wide and 3 ft. high at a distance of 500 ft. ahead. Under adverse conditions, wet or dirty windshield, defective eyesight, facing oncoming headlights, etc., a minimum of 50,000 cp. appears entirely justifiable.

To compensate for light losses due to depreciation of reflectors and bulbs, wet and dirty lenses, low voltage and similar factors, the design value should be at least 100,000 cp.

To be effective, this high candlepower must fall directly upon the object which the driver must see to proceed safely. Obstacles are most frequently located directly ahead of the vehicle at approximately the level of the head-lamp centers. This, then, is the direction which the maximum intensity must take to serve to best advantage. To provide adequate foreground lighting and to show the way around turns, the intensity must shade off downwardly and to both sides, as shown in Fig. 1. To reveal obstacles when approaching an up-grade, the intensity must shade off upwardly to a level substantially above the head-lamp level. These are the requirements for safe driving when the driver has the road to himself.

Requirements for Meeting

While the clear-road beam just described serves admirably when the driver is alone on the road, it would not be at all suitable for use when meeting another vehicle. At close range, both drivers would be blinded and its purpose would be defeated. To drive safely under such conditions, the amount of light directed into the eyes of others must be relatively low. For this situation, an entirely different type of beam is needed.

In actual practice, cars traveling at relatively high speed over dark country highways slow up very little upon meeting an occasional vehicle. Consequently, it is just as necessary to see obstacles and turns 500 ft. ahead as when the driver has the road to himself. In such a case, however, the driver does not have to depend entirely upon the light from his own head-lamps. The oncoming head-lamps help a good deal in lighting the more-distant objects. Furthermore the need for distant visibility is confined largely to the right side of the road.

The beam best suited for meeting occasional cars at the higher speeds which usually prevail on deserted country highways is one aimed low on the left, as shown in Fig. 2, to keep the light below the other driver's eyes, and high on the right, preferably with added intensity on that side, to reach well ahead and cut through the unavoidable glare from the approaching head-lamps. Occasional glare when meeting on right turns is far more than offset by the added visibility range on the right at all times.

Requirements for City Driving

For the more favorable conditions encountered in traveling at relatively low speed over lighted city streets and in heavy traffic where other head-lamps light the way, a third beam, as shown in Fig. 3, aimed low all the way across the road, serves nicely for continuous use with minimum glare hazard. This same beam may be used to avoid glare when meeting on right curves in the country. Parking lamps should never be used alone, even under these favorable conditions, because of their low brightness and lack of attention-attracting power.

Review of Headlighting Developments

The reduction of these basic headlighting principles to practice is necessarily a slow and tedious process because of the time required to retire the older equipments and practices from service. If we could start all over again and forget what had been done in the past, it would be very much similar. Unfortunately that is impossible.

A review of developments in the headlighting field over the period of years since controlled headlighting first appeared on the scene, should be helpful in determining the present status of the problem, what has been done and what remains to be done to complete the job.

Single-Beam Headlighting: Years ago, when cars were few, speeds were low and drivers sat well above the road, it was hoped that a single head-lamp beam might be so arranged as to compromise to fair advantage between the conflicting road illumination requirements and glare limitations.

Head-lamps were developed to fan the light out sideways into a shallow horizontal band, wide enough to show the way around turns and deep enough to provide adequate foreground lighting. Upwardly-directed light, needed to show up obstacles above the head-lamp level on level roads and when approaching an up-grade, was sacrificed out of consideration for glare. The beam was arranged to cut the light

Headlamp-Beam Candlepower versus Visibility Distance

Test Object: 3 Ft. High and 1 Ft. Wide

Visibility Distance, Ft.	Reflection Factor[1] 3.7 Per Cent: Observer No. 1	2	3	4	5	Average	Reflection Factor[2] 14 Per Cent: Observer No. 1	2	3	4	5	Average	Reflection Factor[3] 27 Per Cent: Observer No. 1	2	3	4	5	Aver.
	Cp.	Cp.	Cp.	Cp.	Cp.	Cp.	Cp.	Cp.	Cp.	Cp.	Cp.	Cp.	Cp.	Cp.	Cp.	Cp.	Cp.	Cp.
150	790	980	1,900	2,300	3,400	1,874	180	260	420	500	900	452	90	130	200	310	450	236
200	1,800	2,200	4,400	5,200	7,800	4,280	430	600	960	1,100	2,000	1,018	210	300	460	720	1,050	548
250	3,500	4,300	8,200	10,000	15,000	8,200	810	1,150	1,800	2,150	3,900	1,962	400	580	900	1,350	2,000	1,046
300	6,000	7,200	14,000	17,000	25,000	13,850	1,400	1,900	3,100	3,700	6,300	3,280	680	980	1,500	2,300	3,400	1,772
400	14,000	16,500	32,000	38,000	.....	.....	3,200	4,400	7,000	8,400	15,000	7,600	1,600	2,250	3,500	5,300	7,700	4,070
500	26,000	31,000	.....	.....	.....	.....	6,000	8,200	13,500	16,000	29,000	14,540	3,000	4,300	6,600	10,000	14,500	7,680
700	.....	.....	.....	.....	...	.....	16,000	22,000	35,000	43,000	.....	.....	8,000	11,000	17,000	27,000	38,000	20,200
1,000	.....	.....	.....	.....	.....	...	45,000	.....	.....	.....	.....	.....	23,000	31,000	.....	.....	.....	.....

[1]Represents a person in dark clothing, [2]a person in medium-light clothing; [3]a person in light clothing.
Optical rating of observers in per cent of normal vision, based on a Snellen chart. No. 1, unknown; No. 2, 109 per cent; No. 3, 94 per cent; No. 4, 57 per cent, and No. 5, 23 per cent. The test was made with the car stationary and the object approaching on a straight, level concrete road. There was no moonlight. The observers were accustomed to road illumination before readings were taken.

Fig. 1 *(left)*—**Clear Road Beam**

Maximum intensity aimed high enough to reveal persons and turns at least 500 ft. ahead. Light shades off downwardly, sideways, and upwardly to provide adequate foreground lighting, show the way around turns and reveal obstacles when approaching an up-grade.

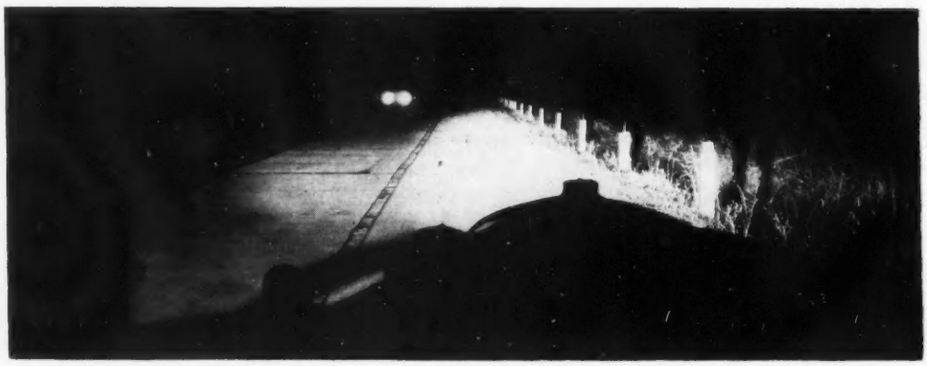


Fig. 2 *(right)*—**Meeting Beam**

Aimed low on the left to avoid glare when meeting. Aimed high on the right with added intensity to show up obstacles and turns ahead.

off as sharply as possible above the maximum-intensity zone. The maximum intensity was then aimed as much below the head-lamp level as was necessary to keep the top of the beam below that level at all times.

It is about 15 years since the single-beam practice was first hailed as the solution to the headlighting problem. Technical societies sponsored it and developed specifications around it. Legislature hastened to incorporate it in laws. Industry designed and built headlamps in conformity with it. Enforcement organizations set about putting it into practice. Thousands of state supervised adjusting stations were created. State-trained service men were provided to man them. Police officers checked head-lamps on the road and sent in customers by the thousands. Newspapers and periodicals were very generous with their publicity. All in all, the single-beam system certainly enjoyed every opportunity to prove its merit.

Accuracy of Assemblies Improved

Time passed and night driving conditions failed to improve as anticipated. Inaccurate head-lamps were blamed. Manufacturers responded by producing lenses, bulbs, reflectors and assemblies to a degree of accuracy believed impossible in mass production. The very latest development along this line is the pre-focused bulb which is standard equipment in many of the 1934 head-lamps.

It was claimed that the adjustment procedure was too complicated. Head-lamp designs were developed to eliminate the focusing device and leave only the relatively simple operation of aiming the beams. This involved a decided sacrifice in light output which had to be offset by changing from the 21 cp. to the 32 cp. bulb at an appreciable increase in the cost of the electrical system.

Today, the large majority of the head-lamps in service are capable of being adjusted to function as intended and will stay in adjustment indefinitely, barring accident. Meantime, speeds have increased, cars have become more numerous and drivers' seats have been lowered—all factors tending to make the job of the single-beam more hopeless.

It was not until these associated troubles were cleared up that the inherent deficiencies in the single-beam system became generally evident; deficiencies arising from the fact that all roads are not level and that the beam level changes substantially with rear seat loading.

Under ideal conditions, when traveling over a strictly level road with the rear seat fully loaded, as shown in Fig. 4, the maximum intensity is directed just below the eyes of the oncoming driver. Dangerous glare is avoided and road illumination is adequate for all reasonable speeds. Each time the vehicle passes over a slight inequality in the road surface or tops a rise, the blinding intensity is directed into the eyes of the oncoming driver. In approaching an up-grade the visibility range is foreshortened to an alarming extent.

Remove the load in the rear seat, and in the case of the more-numerous smaller cars, the beam drops as much as 4 or 5 ft. at a distance of 200 ft. ahead.
The average headlamp is only 3 ft. above the road surface so that the top of the beam then strikes the level road at a distance of 120 to 150 ft. ahead. The maximum intensity from the better types of head-lamps then strikes the level road about 75 ft. ahead of the vehicle.

Two-Beam Headlighting: Granting that the single-beam system is inherently deficient in that it neither provides safe road illumination nor avoids dangerous glare under many ordinary conditions of travel, the alternative was that of

providing two or more beams, one aimed high enough to reveal obstacles and turns at a safe distance ahead, as shown in Fig. 3, another aimed low enough to really avoid glare, the driver to be responsible for using the proper beam at the right time.

It was decided that the two-beam system was worthy of a fair trial. A serious problem was that of handling the situation in such manner as not to interfere with the single-beam practice still in effect in some of the states. From the production standpoint, it was not feasible to distribute different head-lamps in different states. The sharply defined upper cut-off, present in the upper beams from all conventional two-beam head-lamps, was the sacrifice imposed by the need for adapting such head-lamps to the single-beam practice. Today, multiple-beam head-lamps are available on more than 75 per cent of the cars on the road.

Asymmetrical-Beam Head-lamps: Deficiencies in the range of the lower beam from two-beam head-lamps suggested the need for further improvement. The meeting beam, as shown in Fig. 2, was added to avoid glare on the left without sacrificing visibility distance on the right. It met with immediate approval and is already standard equipment on nearly all makes of cars.

Attitude of the Motoring Public

Experience with the single-beam practice in states where it has had a fair trial has demonstrated conclusively that it does not have the backing of the motoring public. Even wholesale arrests have failed to create any lasting interest. Long experience has also demonstrated that no substantial or lasting improvement can be anticipated without the full support of the motorist.

Experience in other safety fields has shown that the average individual can be induced to cooperate when he can be convinced that it is to his advantage to do so. Experience with the multiple-beam practice in some parts of the country proves that it incorporates the elements needed to satisfy the motorist. This is the practice to which the motoring public naturally gravitates if permitted to work out the situation without guidance. Conditions in states like Michigan, where the multiple-beam practice is specified by law, are surprisingly good.

They prove that the average motorist can be trusted to show proper respect for the safety of others if permitted to do so. Considering the handicaps imposed by head-lamp designs which always favor the single-beam practice where two conflict, absence of adjustment facilitates and lack of enforcement, we can visualize readily the possibilities in the multiple-beam system, were it to enjoy a fair opportunity to prove its value under the highly favorable conditions which prevail in certain single-beam states where enforcement is active.

Attitude of Technical Societies

The Society of Automotive Engineers and the Illuminating Engineering Society, original sponsors of the single-beam practice, have abandoned it in favor of the multiple-beam practice. Performance specifications for 1930 state that dual-beam requirements and limitations are based on head-lamp beams aimed with no loading allowance; in other words, beams aimed above the head-lamp level with the rear seat loaded. More recent specifications on asymmetrical type head-lamps remove all glare limits on the clear road beam and openly advocate the multiple-beam practice in the introductory paragraph.

Fig. 3 *(left)*—Lower Beam

Aimed low all the way across the road. Avoids glare and the nuisance of dimming when used continuously under favorable conditions when other lamps help to light the way.

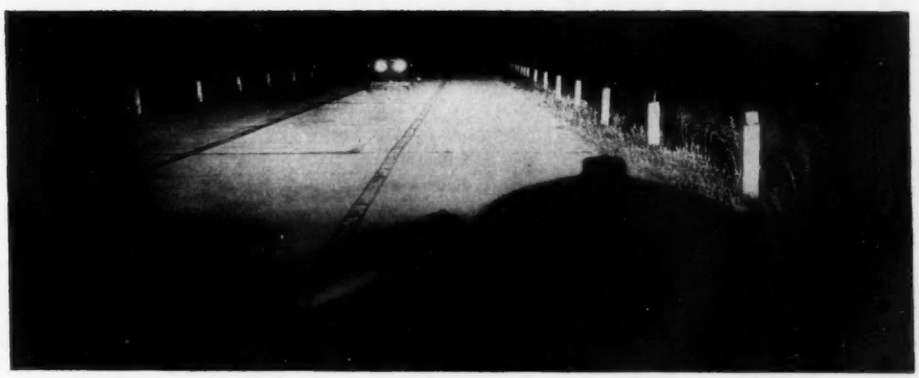


Fig. 4 *(right)* — Single-Beam Compromise

Entire beam aimed low enough to avoid glare on level roads. Light shades off downwardly and sideways to provide adequate foreground lighting and to show the way around turns. Neither provides safe road lighting nor avoids dangerous glare under many ordinary conditions of operation.

Present Headlighting Situation

Summarizing the above, it appears that the automotive industry, in cooperation with interested technical societies and state enforcement organizations, has been very active in establishing the fundamental requirements underlying good headlighting and in developing and distributing head-lamps capable of satisfying these requirements.

That there has been no corresponding degree of improvement on our roads at night is due to the fact that other phases of the problem have not received the same careful attention. It is not enough to provide head-lamps capable of producing satisfactory results in service. It is essential also that these head-lamps be properly serviced and used.

Legislative and Administrative Situation

The legislative and administrative situation is badly in need of attention. There are a few states in which the laws specify the single-beam practice, where an honest and sincere effort is being made at enforcement. There are other states in which the laws specify the single-beam practice, where no serious effort is being made at enforcement. There are still other states where the laws specify the multiple-beam practice, but in no such state is the law supplemented by educational work and enforcement.

Un-enforced single-beam legislation is a decided menace to safety and progress. It leads to all of the ills of the multiple-beam practice without its compensating features. A fundamental single-beam requirement is that head-lamps be maintained in highly accurate adjustment. Lacking enforcement, the natural tendency on the part of the average motorist is to aim the driving beam high enough to see obstacles and turns at a safe distance ahead, in other words, in accordance with the multiple-beam practice. When such aiming is permitted, it is obviously wrong not to require the use of the lower beam in passing. Where enforcement is lacking the law should specify the multiple-beam practice.

The Service Situation

The head-lamp service situation presents a peculiar problem. Here, during these years of depression, we see a potential market involving millions of dollars in profit every year, almost totally neglected in all but the few states where single-beam enforcement is active. In service stations, we see any number of head-lamps with cracked lenses, dirty reflectors, and darkened bulbs, obviously in need of attention. Closer observation discloses low voltage and improper adjustment. In fact, we have no difficulty in finding something seriously wrong with the headlighting on the large majority of the cars which have been in service a year or more. The service man asks about brakes, spark-plugs, oil, and other items not in plain sight but which he knows require attention from time to time. If he turns on the lights, it is merely to determine whether a bulb has failed.

A fundamental principle which appears to have been disregarded in past efforts to promote proper head-lamp adjustment and usage is that the demand for maintenance service originated largely with the service man. Given reasonable assurance that one could give a customer value for his money and make a fair profit on the deal, there appears to be no good reason why the average service operator should overlook this opportunity.

The difficulty appears to arise from the fact that average service adjustment justifies only a nominal charge as compared to the time and expense involved in doing a good job. Occasional sales of bulbs, lenses and reflectors help but not enough to make the job really attractive. What is needed is a relatively inexpensive line of generally applicable replacement parts designed to make available on cars the newer lighting features as they appear on succeeding models. This is a matter which is receiving attention.

Another difficulty is the need for providing a space about 40 ft. long and 8 ft. wide, darkened at one end, in which to do the job. Few service stations can afford to keep such a space available at all times for this purpose. Also, mechanics must be familiar with the variety of head-lamp designs on cars, single-beam, dual-beam, three-beam, and four-beam units, fixed-focus, single-focus, and double-focus types, which have been marketed at various times. An obvious need is a simple and foolproof device which will serve to adjust any and all head-lamps within the space normally available ahead of a car. This is a problem which is receiving careful attention.

With service stations in a position to provide satisfactory service on a sufficiently profitable basis to interest them in bringing this feature to the attention of their customers, a major deficiency which has served very effectively in the past to discourage head-lamp adjustment and maintenance will have been eliminated.

Educational Needs

From long experience, motorists generally appear willing to consider the headlighting situation as hopeless, accepting dangerous glare and unsafe road illumination as necessary evils. Those more familiar with the problem, who maintain their head-lamps in efficient operating condition and in correct adjustment and who use the proper beam at the right time, know that nothing could be farther from the truth, as evidenced by the tendency on the part of such individuals to make their longer trips at night by choice. Actually, those of us who live in the large part of the country where the multiple-beam practice is already permissible, and who are fortunate enough to be driving any car produced within the last four years and many of the cars produced prior to that time, have no one to blame but ourselves if we are not enjoying reasonable safety and comfort in driving at night.

What we need now is an intensive educational campaign designed to familiarize the motoring public with the advantages in the proper maintenance, adjustment and usage of the head-lamps which we have made available on their cars. The facts brought out in this paper were presented to the National Safety Council at its Annual Meeting in October by its Headlighting Committee, with the recommendation that that organization interest itself in the educational side of the program. Recognizing its responsibility in this field, the National Safety Council, with its many contacts throughout the country, agreed to supervise such an intensive educational campaign provided it could be assured of the full support of the automotive industry in helping to distribute the information and in absorbing its fair share of the expense.

Thus the final step in bringing our headlighting efforts to a successful conclusion appears assured. Considering the tremendous amount of time and money which the automotive industry has expended in the past years in bringing the situation to this final stage and considering the advantages in the completed program from the standpoints of reduced accident hazard and increased vehicle usage, there appears to be little reason to expect that the automotive industry will not be willing to assume its fair share of the burden in bringing the matter to a successful conclusion.

Altitude Performance of Aircraft Engines Equipped with Gear-Driven Superchargers

By R. F. Gagg and E. V. Farrar
Wright Aeronautical Corp.

THE rapidly increasing use of aircraft engines fitted with superchargers for improving the power output at high altitudes has focused attention on means for predicting their performance in advance of actual flight tests in an airplane. A considerable amount of engine testing has been performed in several well-equipped laboratories in the past. These results have been carefully compared to determine the degree of similarity of the performance of these engines, and to form conclusions from which the performance of other engines may be predicted. Since the gear-driven centrifugal supercharger has demonstrated its superiority for use at moderate altitudes over other types on the grounds of simplicity, capacity, weight and space requirements, the data considered are almost entirely concerned with this type. It is shown, however, that naturally aspirated engines have quite similar characteristics.

The test results examined indicate that if the horsepower output is determined at any one altitude, the horsepower output for the same engine speed at other altitudes may quite accurately be computed by a simple formula or by use of graphic methods.

Many engines are fitted with superchargers capable of producing such high manifold pressures that the engines cannot be run at full throttle at sea level. For such engines, means are developed for making tests at sea level with a moderate outlay for equipment, from which the altitude performance may be predicted with substantial accuracy.

The methods described in this paper are believed to be simple and accurate enough for general engineering use, and may aid in checking results during the progress of research work.

IN recent years there has been a marked tendency toward the use of supercharged engines in most types of civil and military aircraft. Current standards of performance for the classes of aircraft which normally operate at altitudes in excess of 5000 ft. practically exclude the use of naturally aspirated engines. It becomes increasingly important, therefore, to be able to predict airplane performance at high altitudes in advance of actual flight testing. By means of computations based on wind-tunnel tests and flight experience, the power requirements of an airplane may be calculated with a reasonable degree of accuracy for any altitude, and the engine performance may likewise be predicted from sea-level tests.

Early experience in attempts to supercharge engines for materially increased output at high altitudes showed promising results for both geared centrifugal blowers and displacement blowers of the vane and Roots types. However, increasingly severe restrictions on the total weight of the powerplant per horsepower delivered, and because of the relative simplicity with which the geared centrifugal blower may be incorporated in the conventional types of engine structure without substantial increase in the space requirements, this type has been used more frequently than any other. The inherent flexibility in capacity, the ease with which the degree of supercharging may be altered, simplicity of necessary control mechanism, mechanical reliability and relatively low power losses at part load, have likewise contributed materially to its widespread use. This discussion is, therefore, largely concerned with engines fitted with geared centrifugal superchargers.

Altitude-Laboratory Apparatus and Tests

A large part of the available data on tests to determine the performance of engines at high altitudes has been obtained by an approximation of altitude conditions at the carburetor air-intake and at the exhaust ports. The usual dynamometer equipment is employed for the measurement of engine power-output. During these tests the carburetor air-supply is generally cooled to a low temperature to reduce the water-vapor content to an appropriate value, and the air is then heated electrically to the altitude standard temperature before it is introduced into the carburetor intake. The altitude standard pressure is maintained by throttling the airflow in the duct leading to the carburetor. The engine exhaust gases are gen-

[This paper was presented at the International Automotive Engineering Congress, Chicago, Sept. 4, 1933.]

erally mixed with a water spray to reduce their temperature and are then conducted to a vacuum pump of capacity sufficient to maintain altitude standard pressure in the exhaust manifold. A satisfactory approximation of atmospheric conditions at altitude is thus provided for the induction and exhaust system. Refrigeration and pumping apparatus of considerable capacity are required for the larger engines because of the low difference between the standard temperature for air at high altitudes and the surface temperature of the refrigerating apparatus.

Some liquid-cooled engines have been entirely enclosed in a chamber maintained at altitude temperature and pressure; but, thus far, no large air-cooled engine has been tested in this manner because of the physical difficulties involved. A few foreign laboratories are equipped to maintain the cooling air for relatively small engines at altitude values of temperature and pressure, but there are no similar installations in this country. The principal objection to the use of cooling air at sea-level temperature and pressure is that such tests fail to indicate at what altitude and degree of supercharging the cylinder cooling will prove to be inadequate. It is widely recognized that the reduction of density of the air at high altitudes is a restricting hazard in the use of air-cooled engines. However, it is believed that laboratory and flight conditions vary so widely with respect to the flow of cooling air around the engine that no attempt to simulate actual flying conditions in the laboratory would satisfactorily approach the conditions of an actual flight test.

Because of some conflicts in the various methods of test and computation of engine performance used in the past, it seems appropriate to examine again the published data on this subject in order to compare it with more recent results obtained with current engine designs, and to form conclusions from which the performance of other engines may be predicted.

The results of a number of altitude power calibrations of several different types of engines are shown in Fig. 1. The brake horsepower at constant speed and full-open throttle is plotted with the atmospheric-density ratio ρ/ρ_0 as the abscissa, ρ and ρ_0 being, respectively, the density at any altitude A and at sea level under standard conditions of temperature, pressure, and humidity. This method of plotting is used solely as a matter of convenience, as it will be observed that the relation of horsepower and atmospheric density for standard altitude conditions is a straight line in the range from sea level to 20,000-ft. altitude within the limits of experimental accuracy. This convenient relation is well established by the data presented, and is believed to be practically true for conventional four-cycle spark-ignition aviation-engines of either air-cooled or liquid-cooled types.

With the fact established that brake-horsepower values under standard conditions plotted against the corresponding density ratio are straight lines, it is of interest to determine whether the rate of variation with altitude shows any degree of regularity for the several types of engines. Consideration of the data available shows that, for practically all of the engines with centrifugal superchargers—at the speeds investigated—the brake horsepower decreases uniformly to 47 per cent of the sea-level value at 20,000-ft. altitude. This is also true for the naturally aspirated engines on which data are

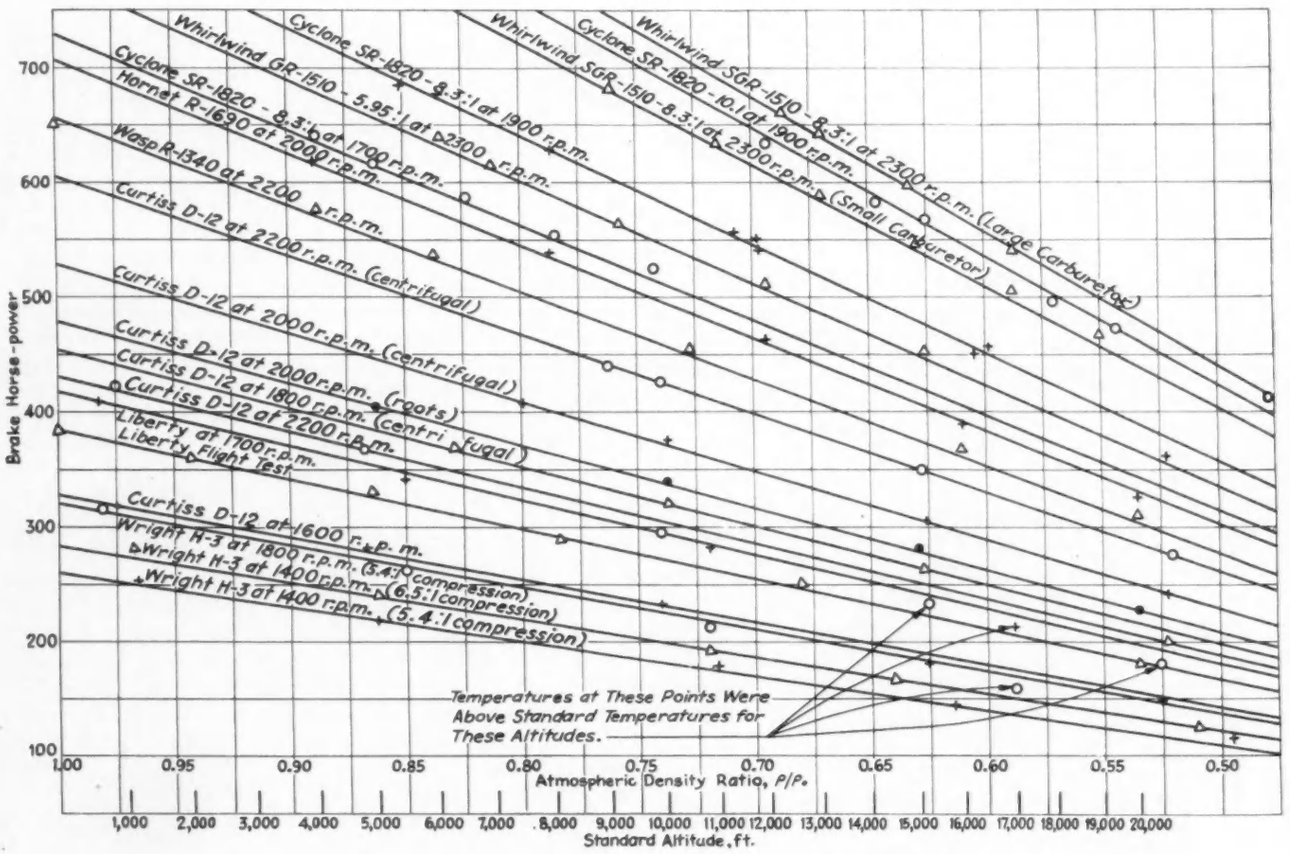

Brake Horse-power
700
600
500
400
300
200
100
Whirlwind GR-1510 - 5.95:1 at 2300 r.p.m.
Cyclone SR-1820 - 8.3:1 at 1900 r.p.m.
Whirlwind SGR-1510 - 8.3:1 at 2300 r.p.m. (Large Carburetor)
Whirlwind SGR-1510 - 10.1 at 1900 r.p.m.
Cyclone SR-1820 - 8.3:1 at 2300 r.p.m. (Small Carburetor)
Cyclone SR-1820 - 8.3:1 at 1700 r.p.m.
Hornet R-1690 at 2000 r.p.m.
Wasp R-1340 at 2200 r.p.m.
Curtiss D-12 at 2200 r.p.m. (centrifugal)
Curtiss D-12 at 2000 r.p.m. (centrifugal)
Curtiss D-12 at 2000 r.p.m. (roots)
Curtiss D-12 at 1800 r.p.m. (centrifugal)
Curtiss D-12 at 2200 r.p.m.
Liberty at 1700 r.p.m.
Liberty Flight Test
Curtiss D-12 at 1600 r.p.m.
Wright H-3 at 1800 r.p.m. (5.4:1 compression)
Wright H-3 at 1400 r.p.m. (6.5:1 compression)
Wright H-3 at 1400 r.p.m. (5.4:1 compression)
Temperatures at These Points Were Above Standard Temperatures for These Altitudes.
1.00 0.95 0.90 0.85 0.80 0.75 0.70 0.65 0.60 0.55 0.50
Atmospheric Density Ratio, P/Po
1,000 2,000 3,000 4,000 5,000 6,000 7,000 8,000 9,000 10,000 11,000 12,000 13,000 14,000 15,000 16,000 17,000 18,000 19,000 20,000
Standard Altitude, ft.

Fig. 1—Comparison of Published Data on Altitude Performance of Several Types of Aviation Engines

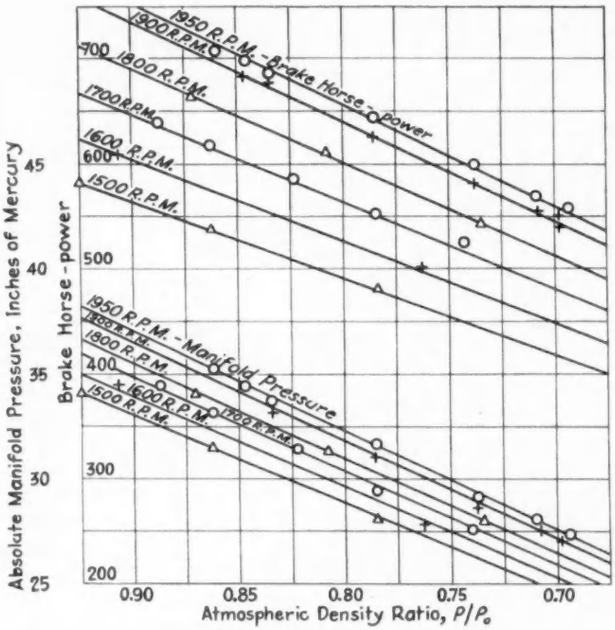


Fig. 2—Results of Altitude-Performance Calibration of Cyclone SR-1820 Engine with 6.4:1 Compression Ratio and 8.3:1 Blower Gear-Ratio

available. This relation may be expressed mathematically by the equation:—

$$\text{Hp.} = \text{Hp.}_o \left[\frac{\rho}{\rho_o} - \frac{\left(1 - \frac{\rho}{\rho_o}\right)}{7.55} \right] \qquad (1)$$

Hp. = Horsepower at altitude A
Hp._0 = Horsepower at sea level
ρ_0 = Atmospheric density at altitude A
ρ = Atmospheric density at sea level

Equation (1) represents a family of straight lines intersecting in a point at zero brake horsepower and 0.117 density-ratio. However, few experimental data are available to show how far above 20,000-ft. altitude the relation may be valid. The fact that the lines intersect in a point would appear to indicate that that part of the friction losses due to fluid friction and to inertia and centrifugal loads is substantially constant for all modern types of aircraft engines. While the relation expressed by Equation (1) is entirely empirical, it is probably sufficiently accurate for use in predicting the altitude performance of an aviation engine for engineering purposes. The values obtained by use of Equation (1) are shown in Table 1, for several altitudes.

Fig. 2 shows a series of runs made at various speeds with wide-open throttle and altitude conditions at the carburetor intake and at the exhaust ports. The results are plotted in a manner similar to that used in Fig. 1. It will be noted that the absolute pressures in the intake manifold also plot as straight lines, with atmospheric-density ratio as the abscissas. The rate of decrease with change in atmospheric-density ratio is generally not as consistent as for the brake-horsepower curves. However, it will be shown later that reasonable accuracy may be expected if the manifold-pressure curves are assumed to decrease with altitude at the same rate as do the horsepower curves; that is, to 47 per cent of their sea-level value at 20,000 ft.

Data are shown in Fig. 3 for the results obtained with one type of engine when the supercharger-driving gear-ratio is varied through a considerable range. These tests clearly illustrate the importance of providing liberal areas throughout the induction system if the full benefits of supercharging for high-altitude performance are to be realized in flight. The smaller of the two carburetors is amply proportioned for sea-level operation; but the larger carburetor—56-per cent throat-area increase—produces a marked improvement in performance at high altitude. It is obvious that a poorly proportioned air-intake duct leading to the carburetor will have an effect similar to that caused by the small carburetor.

Table 1—Values Obtained from Equation (1)

Altitude Ft.	ρ/ρ_o	Horsepower Correction Factor
Sea Level	1.000	1.000
1,000	0.971	0.967
2,000	0.943	0.935
3,000	0.915	0.904
4,000	0.888	0.874
5,000	0.862	0.844
6,000	0.836	0.814
7,000	0.811	0.786
8,000	0.786	0.758
9,000	0.762	0.730
10,000	0.738	0.704
11,000	0.715	0.678
12,000	0.693	0.652
13,000	0.671	0.627
14,000	0.650	0.604
15,000	0.629	0.580
16,000	0.609	0.556
17,000	0.589	0.535
18,000	0.570	0.513
19,000	0.551	0.492
20,000	0.533	0.471

In. Fig. 4, the manifold-pressure and altitude-horsepower curves appear in pairs with the members of each pair intersecting at sea level. The upper horsepower curve is the straight-line relation obtained when an engine is run under true altitude conditions, as in Fig. 3, and the lower one is the result obtained when an engine is run with altitude conditions at the carburetor inlet and sea-level pressure at the exhaust ports.

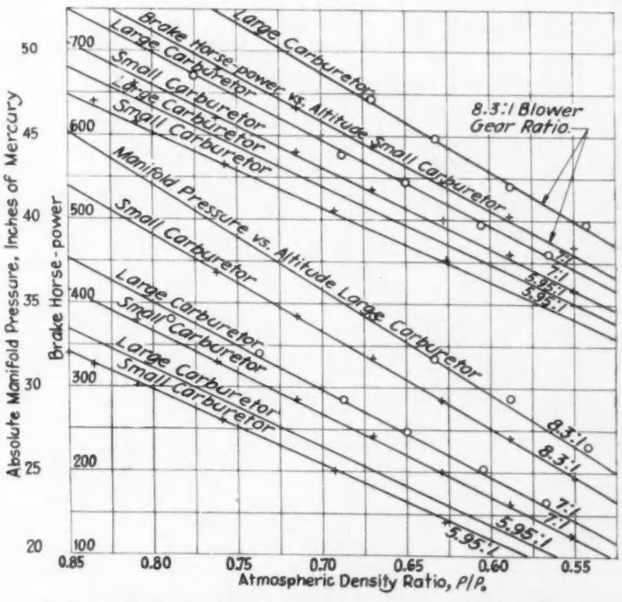


Fig. 3—Results of Altitude-Performance Calibration of Whirlwind SR-1510 Engine with 6.25:1 Compression Ratio, Three Blower Gear-Ratios, and Two Carburetor Sizes

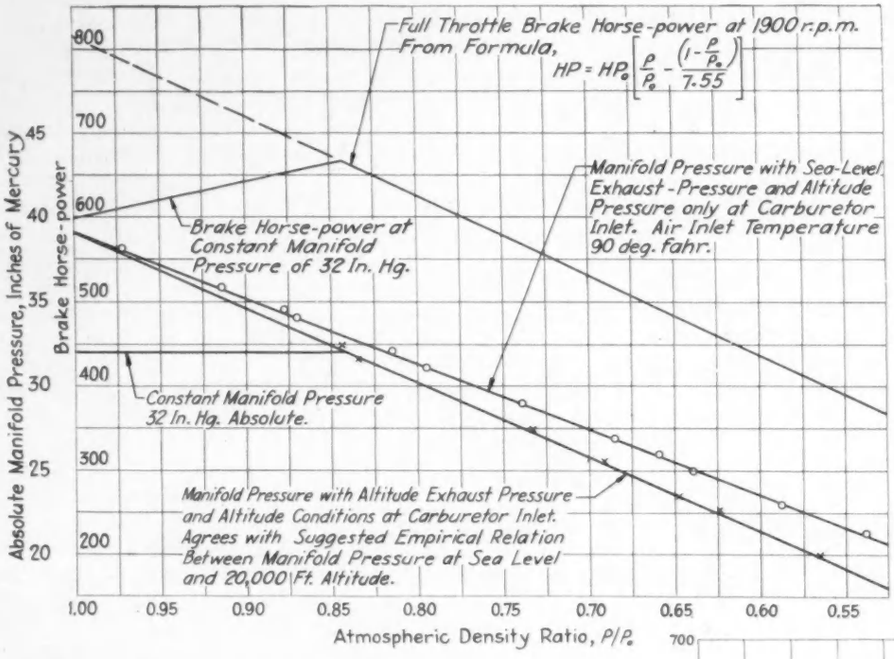
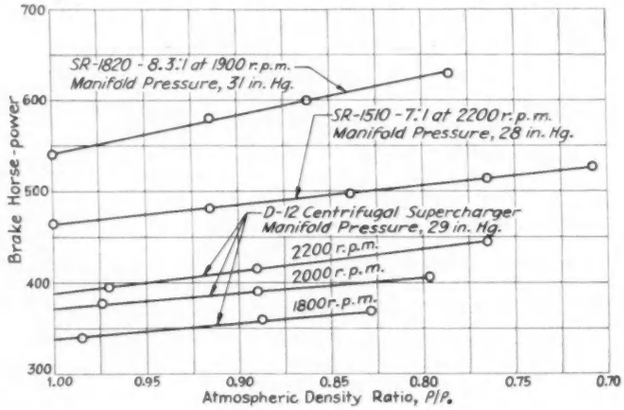

Full Throttle Brake Horse-power at 1900 r.p.m. From Formula, $HP = HP_o\left[\frac{\rho}{\rho_o} - \frac{\left(1-\frac{\rho}{\rho_o}\right)}{7.55}\right]$
Manifold Pressure with Sea-Level Exhaust-Pressure and Altitude Pressure only at Carburetor Inlet. Air Inlet Temperature 90 deg. fahr.
Brake Horse-power at Constant Manifold Pressure of 32 In. Hg.
Constant Manifold Pressure 32 In. Hg. Absolute.
Manifold Pressure with Altitude Exhaust Pressure and Altitude Conditions at Carburetor Inlet. Agrees with Suggested Empirical Relation Between Manifold Pressure at Sea Level and 20,000 Ft. Altitude.
Absolute Manifold Pressure, Inches of Mercury
Brake Horse-power
Atmospheric Density Ratio, P/P_o

Fig. 5 *(left)*—Altitude-Performance Curve Based on Results of Tests at Sea Level with Reduced Pressure at the Carburetor-Air Inlet

Cyclone R-1820 engine with 6.4:1 compression ratio and 7.0:1 blower gear-ratio.

Fig. 6 *(below)*—Variation of Brake Horsepower at Constant Manifold Pressure with Change of Atmospheric Density


SR-1820 - 8.3:1 at 1900 r.p.m. Manifold Pressure, 31 in. Hg.
SR-1510 - 7.1 at 2200 r.p.m. Manifold Pressure, 28 in. Hg.
D-12 Centrifugal Supercharger Manifold Pressure, 29 in. Hg.
2200 r.p.m.
2000 r.p.m.
1800 r.p.m.
Brake Horse-power
Atmospheric Density Ratio, P/P_o

The manifold-pressure curves in Fig. 4 appear to be straight lines for operation with altitude conditions at the carburetor inlet and either exhaust system. The divergence of these curves from their intersection at sea level is due largely to the fact that more air is being pumped by the supercharger with altitude pressure at the exhaust ports. The greater carburetor-pressure drop thus induced and the tendency of pressure to decrease with increased quantity delivered by a centrifugal blower operating at constant speed, combine to give the lower manifold pressure observed.

Several runs made to check the usual assumption that brake horsepower varies as $\sqrt{[(460 + t)/520}$, where t is the temperature of the carburetor-inlet air in degrees Fahrenheit, show that this practice does not introduce material inaccuracy in the range from 30 to 80-deg. fahr. carburetor-air temperature but is considerably in error at higher temperatures. This fact has often been observed, especially in connection with testing air-cooled supercharged engines. The formula was originally intended to be applied to indicated horsepower only, but it has been widely used to correct brake horsepower for variation from the standard air-intake temperature of 60 deg. fahr.

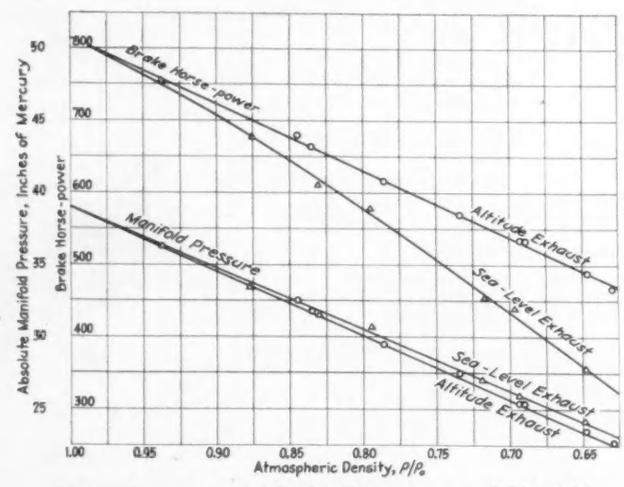


Fig. 4—Comparison of Brake Horsepower and Manifold Pressure Obtained with Standard Altitude Conditions at the Carburetor Intake and Either Sea-Level or Altitude Pressure at the Exhaust Ports

Cyclone R-1820 engine with 6.4:1 compression ratio and 7.0:1 blower gear-ratio.

As noted previously, the apparatus necessary for the calibration of a large aircraft engine under simulated high-altitude atmospheric-conditions is quite complicated and expensive. Tests of this kind are, therefore, limited to a small number of laboratories for the present, at least, which emphasizes the desirability of devising a method for the approximate determination of altitude performance which requires only the usual facilities for power measurement without complicated apparatus for reproducing atmospheric conditions at high altitudes. Fortunately, all engines can be supplied cheaply with plenty of fresh air and this supply can readily be restricted by a simple throttling valve in the duct leading to the carburetor. The apparatus necessary for reproducing altitude pressures at the carburetor intake is, therefore, readily obtainable.

Atmospheric humidity introduces a variable in this sort of testing if substantially dry air is not available. The resulting error in absolute manifold pressure may be partially corrected by computing the absolute manifold pressure as the algebraic sum of the true barometric pressure and the observed mani-

fold pressure (differential from atmospheric), less the atmospheric vapor pressure. This, of course, is only an approximate correction, but it has been found to be sufficiently accurate for the intended purpose.

The manifold pressures obtained by operating with the carburetor-air supply at various altitude pressures and sea-level temperatures, and exhausting directly into the atmosphere at sea-level pressure, are plotted in Fig. 5, together with a similar test with altitude temperature at the carburetor intake and exhausting at altitude pressure. Both sets of data are plotted with the atmospheric-density ratio as abscissa.

Since both sets of data plot as substantially straight lines, they may readily be extrapolated to sea-level density and the lines intersect at this point. The error in the value obtained when the curve run at the atmospheric temperature available extrapolated to sea level is negligible since the effect of temperature on manifold pressure is relatively small, and the temperatures of such a run will not ordinarily be far from standard sea-level temperature. Thus a hypothetical manifold pressure for sea-level conditions with wide-open throttle may be obtained.

A manifold-pressure curve which is a reasonable approximation of the true curve under altitude conditions may be obtained by assuming that the manifold pressure at 20,000-ft. altitude is 47 per cent of the hypothetical sea-level value obtained from the run with reduced pressure. This curve, as explained later, is useful in estimating the critical altitude for the engine and supercharger combination being tested. The use of 47 per cent of sea-level value at 20,000 ft. in plotting the manifold-pressure curve leads to a maximum error of about 3 per cent in critical altitude for the engines on which data are presented.

The horsepower values obtained with sea-level temperature and controlled pressure at the carburetor-air inlet with sea-level exhaust-pressure do not appear to be directly useful since they are subject to a large correction for temperature and a still larger correction for exhaust back-pressure before representing horsepower output at standard-altitude conditions. Since the usual method of correction for carburetor-inlet air-temperature can only be justified over a comparatively narrow temperature range, it is best to eliminate large temperature corrections where possible. The correction for exhaust back-pressure varies so greatly with compression ratio, valve timing and degree of supercharge, that it also appears desirable to eliminate this type of correction if possible.

However, a useful relation between the horsepower obtained in the foregoing type of run and the corresponding manifold pressures is shown in Fig. 7, in which the brake horsepower at sea level is plotted versus absolute pressure in the manifold. From inspection of a large number of these curves it has been found that, for the engines tested, the curves considered in the range of manifold pressures from 15 to 40 in. of mercury, absolute, are not straight lines. But they are practically straight over the range usually encountered in flight operation; that is, from 22 to 35 in. of mercury. At pressures above 35 in. of mercury, the curves for many engines drop below the straight lines, probably due to insufficient cooling and detonation of the fuel. Experience indicates that this type of curve is a valuable aid in checking the performance of an engine, as results obtained are influenced to a

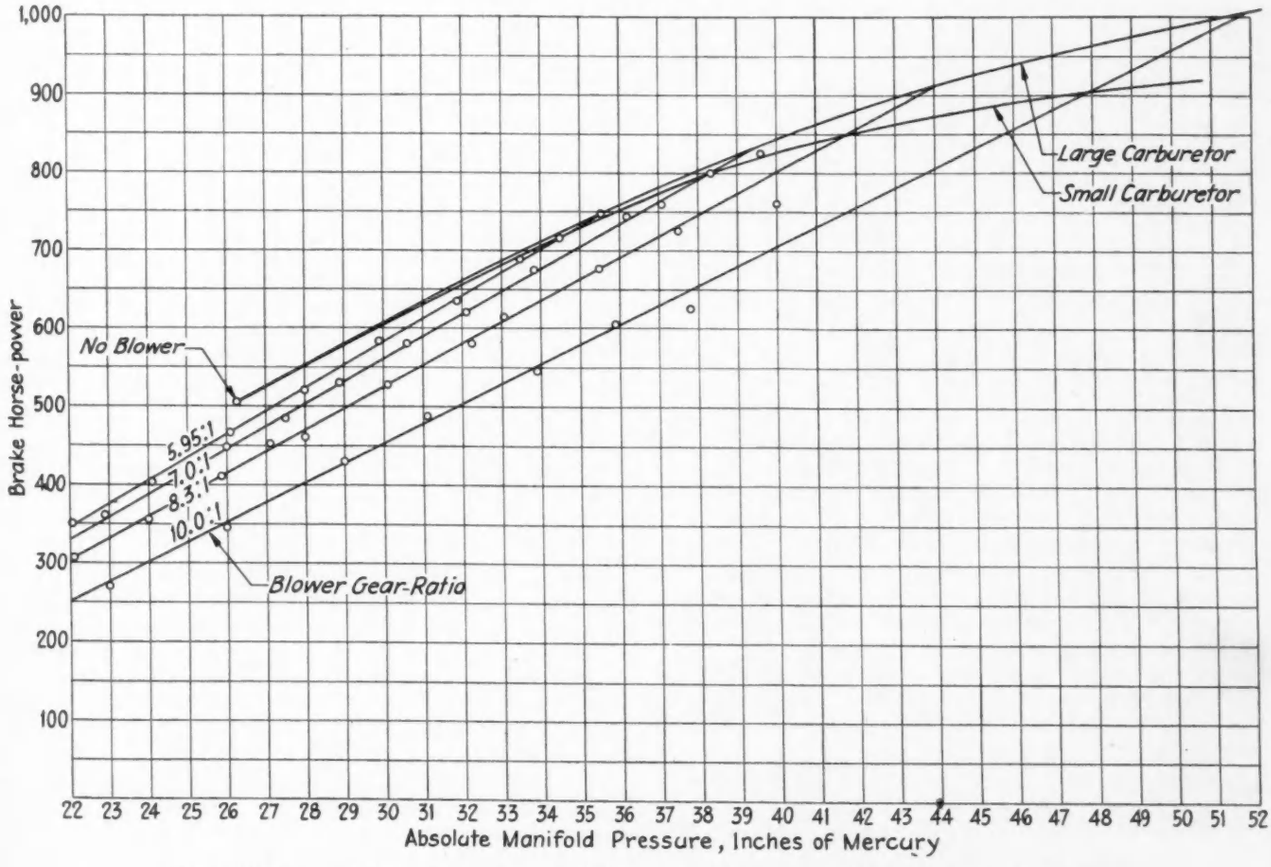


Fig. 7—Variation of Brake Horsepower at Sea Level with Change in Absolute Manifold Pressure
Cyclone SR-1820 engine with 6.4:1 compression ratio, four blower gear-ratios and two carburetor sizes.

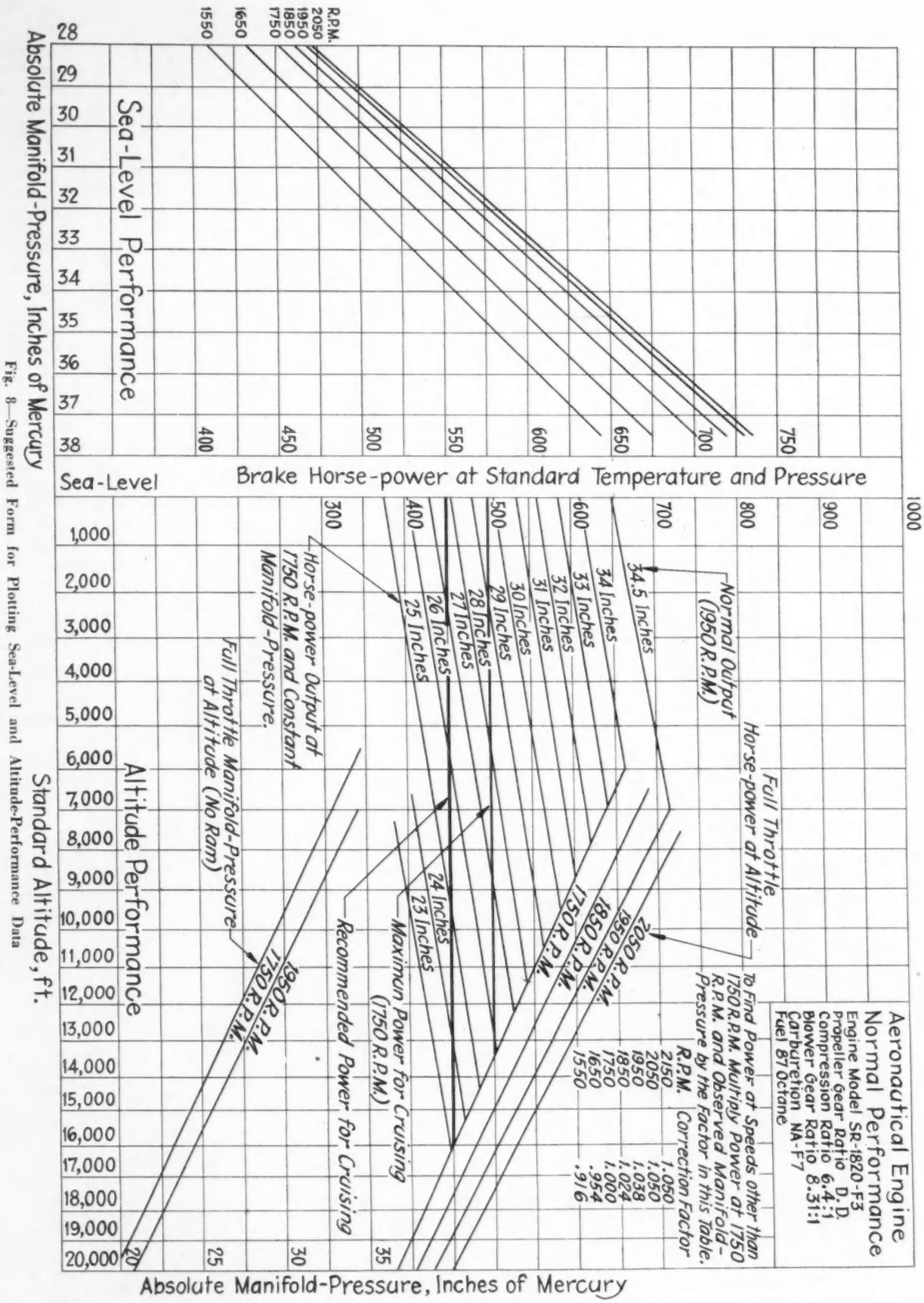


Fig. 8—Suggested Form for Plotting Sea-Level and Altitude-Performance Data

considerable extent by engine-operating conditions. For the same reason, the results of several tests should be considered in establishing "normal" values for engine performance.

To obtain the hypothetical sea-level horsepower for use in the altitude-horsepower equation, it is necessary to extrapolate the curve of sea-level horsepower versus manifold pressure for the engine being tested and to read the horsepower at the hypothetical manifold pressure determined by a run at reduced inlet-air pressure. The straight portion of the manifold-pressure curve from 22 to 35 in. of mercury, absolute pressure, should be used as a guide and the curve extrapolated as a straight line. This is justifiable, since it is assumed in the several extrapolations which are proposed that no basic changes in the nature of engine operation would take place as sea level was approached if sufficient cooling and a fuel capable of withstanding high temperatures and pressures without detonation could be supplied. Such an extrapolation is also in good agreement with the hypothetical manifold-pressure and brake-horsepower results obtained by extrapolating the altitude-test results investigated.

With the hypothetical sea-level horsepower of an engine known, it is a simple matter to plot the curve of brake horsepower at altitude on a density-ratio scale, since it thus becomes a straight line falling to 47 per cent of its sea-level value at 20,000-ft. altitude. The maximum altitude to which a supercharger will maintain a given manifold pressure, or the critical altitude, as it is commonly termed, may be read from the curve of manifold pressure at altitude, determined in the manner already explained.

In the example given, a value of 32 in. of mercury, absolute pressure, has been selected as the limiting value for one grade of fuel. The critical altitude for this pressure is then 5700 ft. and that portion of the full-throttle horsepower curve below 5700 ft. represents horsepower values which cannot be used in practice due to the probability of overheating and overstressing the engine parts.

The horsepower at sea level for 32 in. of mercury manifold pressure may be obtained from data plotted as in Fig. 7, and the horsepower at any altitude below the critical represented by a straight line drawn from the sea-level value at 32 in. of mercury pressure to the value at the critical altitude. Data to substantiate this assumption are shown in Fig. 6. These data were obtained by running the engines with controlled manifold pressure, altitude air-inlet temperature, and altitude exhaust-conditions. It will be observed that these same data, plotted with values of altitude as abscissas, deviate only slightly from a straight line.

A convenient form for showing both the sea-level and altitude-horsepower output of an aircraft engine, based on the methods discussed in this paper, is illustrated in Fig. 8. A moderately supercharged engine has been selected as an example. At the left of the form, a sufficiently wide range of speeds and manifold pressures at sea level are covered to permit a ready determination of power output for normal take-off and flight operation. At the right, a series of full-throttle power versus altitude curves are shown in conjunction with power at a range of manifold pressures at one engine speed. Power at any manifold pressure and speed likely to be obtained in flight may be calculated by use of the table at the extreme right of Fig. 8.

It will be observed that the altitude-horsepower output is plotted against altitude above sea level, but the latter scale graduations are proportional to the standard atmosphere-density ratios. This achieves the convenient straight-line plotting which greatly simplifies the preparation of the data, and extrapolation or interpolation when necessary.

[1] See N.A.C.A. Technical Report No. 46.
[2] See *Journal of the Franklin Institute*, vol. 200, pp. 711-730.

Summary

The preceding discussion has outlined methods applicable to the approximate determination of the altitude performance of conventional aircraft engines in the range from sea level to 20,000 ft., and sample data have been presented to illustrate the methods used. The effects of the principal variables have been evaluated with sufficient accuracy for the purpose of this work and some of the results have been verified by flight testing. The chief items discussed may briefly be summarized as follows:

(1) The variation of brake horsepower with altitude is a straight-line relation when plotted against atmospheric-density ratio, and falls to 47 per cent of the sea-level value at 20,000 ft.

(2) The variation of manifold pressure with altitude is a straight-line relation when plotted against atmospheric-density ratio, and falls to approximately 47 per cent of the sea-level value at 20,000 ft.

(3) A manifold-pressure curve with reduced carburetor-air-inlet pressure and sea-level exhaust may be extrapolated to sea-level density to obtain a hypothetical full-throttle sea-level manifold-pressure.

(4) The brake horsepower at sea level with the foregoing hypothetical manifold-pressure may be obtained from an extrapolation of the curve of brake horsepower at sea level versus manifold pressure, and the brake horsepower at any altitude determined from the equation presented.

The means developed in this paper for the estimation of altitude performance, while admittedly empirical, are believed to be simple and accurate enough for general engineering use and should constitute a considerable aid in checking results during the progress of research work.

Discussion

Altitude Tests of Liquid-Cooled Aircraft-Engines

—H. K. Cummings
Bureau of Standards

THE simplicity of the method proposed by Messrs. Gagg and Farrar for predicting the altitude performance of supercharged air-cooled aircraft-engines makes it very valuable for use where altitude test-data are not available and where the results of approximate altitude tests require considerable corrections for temperature and/or pressure. However, neither the Army, the Navy nor the Department of Commerce, is likely to regard this method of computation as an acceptable substitute for altitude tests, at least until the data presented in this paper and other available data have received critical study. I believe that the authors are somewhat optimistic in claiming that the net results of their computations are within 3 per cent of the actual values.

The altitude testing at the Bureau of Standards has been confined to liquid-cooled engines and, as early as 1920, Gage showed[1] that the results of tests on the unsupercharged Liberty and Hispano-Suiza engines gave approximately straight lines when brake horsepower was plotted against relative density, with zero horsepower at a relative density

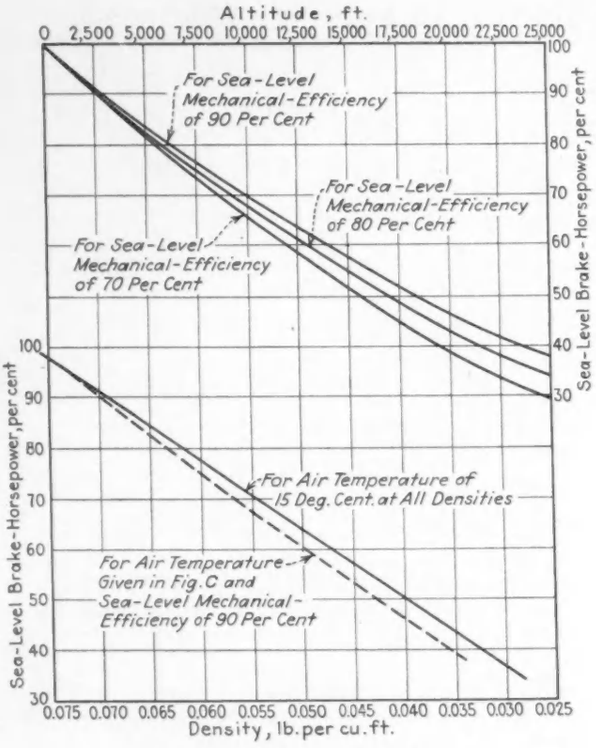

Altitude, ft.
0 2,500 5,000 7,500 10,000 12,500 15,000 17,500 20,000 22,500 25,000
For Sea-Level Mechanical-Efficiency of 90 Per Cent
For Sea-Level Mechanical-Efficiency of 80 Per Cent
For Sea-Level Mechanical-Efficiency of 70 Per Cent
Sea-Level Brake-Horsepower, per cent
For Air Temperature of 15 Deg. Cent. at All Densities
For Air Temperature Given in Fig. C and Sea-Level Mechanical-Efficiency of 90 Per Cent
Density, lb. per cu. ft.
0.075 0.070 0.065 0.060 0.055 0.050 0.045 0.040 0.035 0.030 0.025

Fig. *A*—Brake-Horsepower Curves

The curves in the upper chart represent change of brake horsepower with altitude. When brake horsepower was plotted against relative density, as in the lower chart, the curves approximated straight lines.

of about 0.1. In 1925, Sparrow presented[2] the brake horsepower curves shown in Fig. *A*. The upper curve is identical with the curve which would result from plotting the data presented in Table 1 of the paper, and is based on the following assumptions:

(1) Indicated horsepower at 20,000 ft.; 49 per cent of its sea-level value

(2) Sea-level mechanical-efficiency, 90 per cent

(3) Maximum observed variation of friction horsepower with altitude

In Fig. *B*, the two lower curves show 47 per cent of sea-level indicated-horsepower and 43 per cent of sea-level brake-horsepower at 20,000 ft. The Curtiss D-12 engine had somewhat less than 90 per cent mechanical efficiency at sea-level, and the friction horsepower at 20,000 ft. was 80 per cent of the sea-level value instead of 73 per cent as assumed by Sparrow.

Fig. *C* shows curves of brake-horsepower versus relative density for two Packard engines. The curves for the low-compression engine are fairly linear and give respectively 42, 45 and 48 per cent of sea-level brake-horsepower at 20,000 ft. The values for the high-compression engine are low at 5000 ft., due to detonation and, at 20,000 ft., due to high air-temperature, but the intermediate portion of the 1600-r.p.m. curve indicates that this engine would normally develop less than 40 per cent of sea-level brake-horsepower at 20,000 ft. In recent tests of the Curtiss D-12 engine, varying the jacket temperature from 35 deg. to 95 deg. cent. without any other change in operating conditions was found to increase the percentage of sea-level brake-horsepower at 20,000 ft. from 42 to 45. The foregoing data indicate that the brake-horsepower of unsupercharged liquid-cooled aircraft-engines at 20,000 ft. is from 40 to 48 per cent of the corresponding sea-level values, averaging well below 47 per cent.

That supercharged engines, when operated at full throttle, should show a variation of brake horsepower with altitude similar to that observed for unsupercharged engines is not altogether surprising. Moreover, the extrapolated data from approximate altitude tests of air-cooled engines with cooling air at constant temperature show that the percentage of sea-level brake-horsepower at 20,000 ft. may vary from 39 to 49 for engines of similar design. How these altitude-test results would be affected if the temperature and pressure of the cooling air were varied with altitude has not been determined, but available data on sea-level tests of a given air-cooled engine at different air temperatures indicate that the usual correction for carburetor-air temperature accounts for only about one-third of the total change in brake horsepower.

The Bureau of Standards recently has analyzed the influence of atmospheric conditions on engine power, as shown in Fig. *D*, and has proposed a systematic investigation of the effects on power of intake pressure and temperature, exhaust pressure and mean cylinder-temperature. It is obvious that the effect of atmospheric conditions on each of these quantities will depend to a greater or less degree on engine design and installation, but these effects can be ascertained in any particular case by means of flight tests. Suppose, for example, that the effect on brake horsepower of changes in cylinder temperature and intake-charge temperature were completely evaluated by a comprehensive series of tests at a number of compression ratios, using a liquid-cooled engine operated at

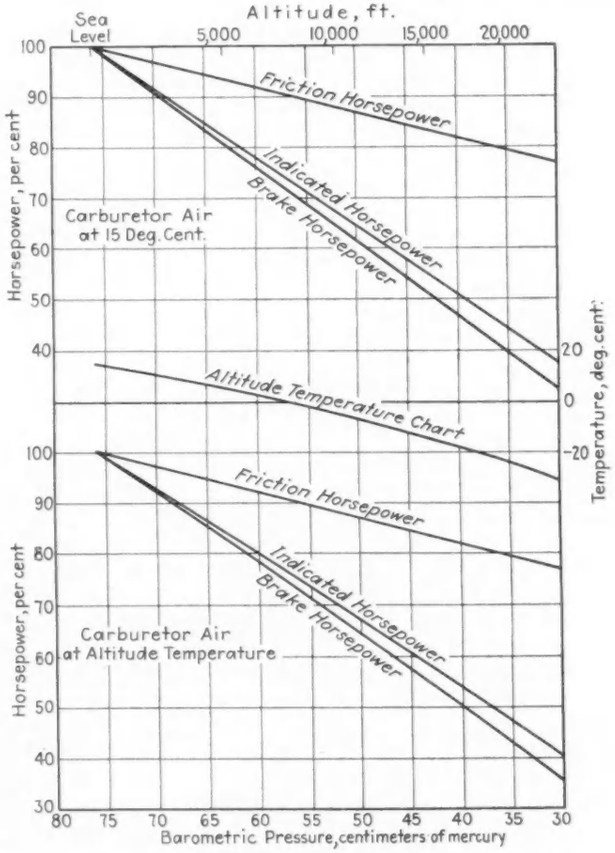


Fig. *B*—Horsepower Curves

The two lower curves show 47 per cent of sea-level indicated-horsepower and 43 per cent of sea-level brake-horsepower at an altitude of 20,000 ft.

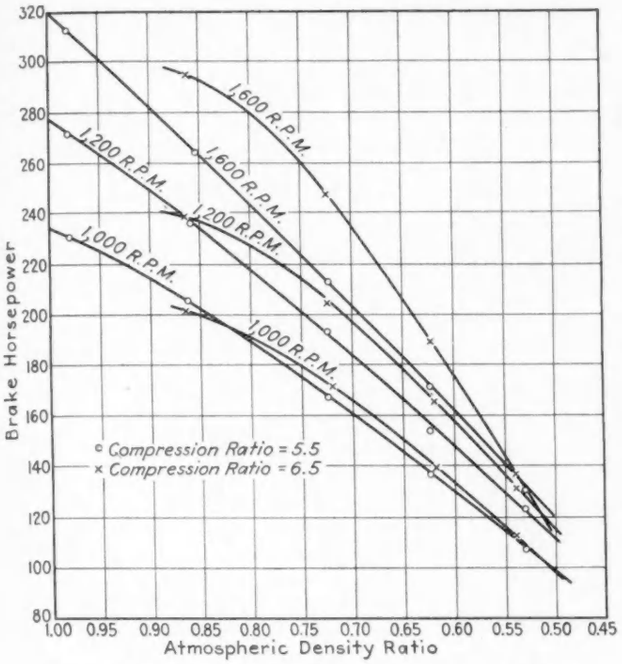


Fig. C—Curves of Brake Horsepower versus Relative Density for Two Packard Engines

various jacket temperatures. To make these results applicable to a certain type of engine and installation, it would be necessary only to determine experimentally for this engine the changes in charge temperature and cylinder temperature produced by known changes in air temperature.

The author's hypothesis that the variation in manifold pressure with altitude obeys the same equation as the variation of brake horsepower implies, of course, a constant ratio of horsepower to manifold pressure. In some of the approximate altitude tests considered, this ratio is nearly constant, but in other tests the manifold pressure appears to change more or less rapidly with relative density (altitude) than does the brake horsepower.

Accuracy of Empirical Formula Commended

—S. R. Puffer
General Electric Co.

CLOSE association with the engineering design of all of the superchargers referred to in this paper makes it particularly interesting to me. The authors are to be congratulated on presenting a remarkably simple empirical solution of a very difficult theoretical problem. The theoretical solution of the problem involves such terms as the effect of temperature and pressure on mean effective pressure, the theoretical power for polytropic compression in the supercharger, the correction of the friction horsepower obtained when the engine is not firing to the equivalent value during a firing cycle of the friction run, and computation of the density in the intake manifold from the atmospheric density, the amount of supercharging and the amount of restriction.

Some of these effects have been considered by Sparrow and Thorne[3], by Gove[4], and by Chenoweth[5]. The authors' empirical formula solves all of these problems at once. It so well represents the tests that, when a complete theoretical solution of the problem is given and is to be compared with actual performances, the formula may be used to represent actual engine-performances. It is interesting to note that the formula is even correct in a general way at very high altitudes. If extrapolated, it gives zero engine power at a density ratio of 0.117. At such a density ratio, the indicated power will be of the general order of magnitude of about 12 per cent of sea-level power, and the mechanical friction for an engine having a mechanical efficiency of 88 per cent will also be 12 per cent of the sea-level power, so that the engine itself would be expected to deliver zero power.

The difference between performances of small and large carburetors emphasizes a point also made in a paper[6] by A. H. R. Fedden, that restricted areas cause a loss of power and that a supercharger should be used to increase the amount of charge and not to neutralize the effect of insufficient areas. It is to be noted that restrictions in the supercharger discharge-pipe, supercharger diffuser, engine inlet-valves or anywhere else in the air passages, are as harmful as at inlet. It is to be noted that the small carburetor causes just as much loss in the power which might be obtained with wide-open throttle at low altitudes as it does at high altitudes. Of course, this power is not missed at low altitudes, because the throttle could not be opened wide anyway.

The authors mention attempts to check the usual formula for temperature correction on the basis of the square root of absolute temperature. I should like to inquire if this check was also tried on the basis of intake-manifold temperature rather than atmospheric temperature.

The authors give also an approximate empirical relation between the pressure produced by a given supercharger at sea level and at any altitude. There is a rather complicated theoretical formula for obtaining supercharger pressure at altitude, which cannot be algebraically simplified. However, substitution of a number of numerical values of sea-level pressure indicates that the authors' formula gives the results of the theoretical formula with the accuracy which they indicate.

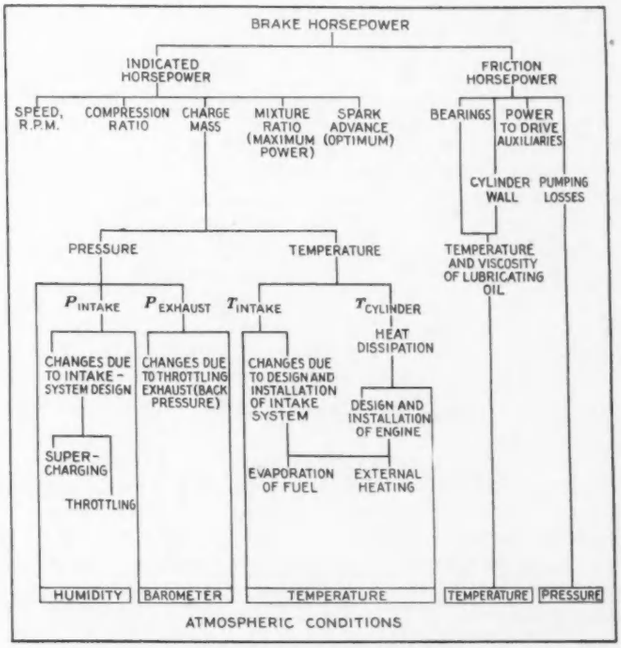


Fig. D—Influence of Atmospheric Conditions on Engine Power

[3] See N.A.C.A. Report No. 262.
[4] See N.A.C.A. Report No. 295.
[5] See S.A.E. JOURNAL, November, 1927, p. 508.
[6] See S.A.E. JOURNAL, December, 1933, p. 377.

Jacobs' Paper Discussion Develops Additional Points Worth Studying

DISCUSSION of the paper, "Aerodynamics of Wing Sections for Airplanes," by Eastman N. Jacobs, is published herewith. The paper was printed in the S.A.E. JOURNAL for March, 1934, pp. 82-91. It was awarded the Wright Brothers Medal for 1933 and considers the air forces acting on airfoil sections, their origin, and the nature of the differences between the air forces acting on an ideal airfoil section and on an actual one.

The effects of viscosity and separation of the flow from the airfoil surface are treated also in the paper which, finally, devotes consideration to the variation of the aerodynamic properties of sections with changes in the section shape.

Laminar Boundary-Layer Separation; and Turbulence

—Clark B. Millikan
California Institute of Technology

THE author and the N.A.C.A. are to be most sincerely congratulated upon the very beautiful series of airfoil measurements summarized in the paper. It is my belief that, from a practical viewpoint, the systematic N.A.C.A. series of airfoils in question is the most important which has ever been investigated. The determination of a thickness function to give good profile-drag properties and based entirely on empirical data seems to be the only rational procedure at present, in view of the inability of any theory to suggest analytical methods of approaching this phase of the problem. The practical importance of these new airfoil sections developed at the N.A.C.A. is attested by the fact that many of the new high-performance airplanes which are currently appearing are designed around them. This is all the more remarkable in that the experimental program is so recent that the paper is the first in which the entire series is discussed.

I was particularly interested in Mr. Jacobs' discussion of the separation phenomenon and the related problem of the maximum lift-coefficient, since he has been actively engaged in experimental and theoretical researches on these questions for the last eighteen months, in conjunction with Dr. Theodor von Kármán and Dr. A. L. Klein of the Guggenheim Aeronautics Laboratory, California Institute of Technology *(Galcit)* staff. It is believed that our researches revealed for the first time the physical basis for the close dependence of $C_{L max.}$ on Reynolds' Number and initial turbulence as residing—at least up to Reynolds' Numbers of the order of two or three million—in a kind of contest between the separation point of the laminar boundary-layer and its point of transition from the laminar to the turbulent regime. These ideas were first presented[1] very briefly by Dr. von Kármán in December, 1932, and have recently been more completely discussed in a paper[2] which gives the results of an extensive experimental investigation of the problem. A paper by Dr. von Kármán and the writer, presenting the theoretical treatment of the phenomena which led to the conception outlined above, is now in manuscript form and will be published in the near future.

Both the writer and Dr. von Kármán had the privilege of having several very valuable oral discussions of these questions with Mr. Jacobs and other members of the N.A.C.A. staff. Mr. Jacobs' presentation is in some respects identical with our considerations as presented in these discussions, but in some points there are essential discrepancies, which it is desired to explain in a little detail.

Separation of the Laminar Boundary-Layer

One conceptual error unfortunately exists in Mr. Jacobs' discussion which results in the incorrectness of the conclusions drawn in the second paragraph of his section on "Separation". The discussion in question deals with the separation of a laminar boundary-layer at such low Reynolds' Numbers that turbulence does not occur to confuse the phenomenon. Mr. Jacobs is led to the ascribing of a displacement of the separation point as the Reynolds' Number varies, through general considerations of the equilibrium between pressure and viscous forces. The interrelationship of these quantities is not quite so simple as Mr. Jacobs assumes, since the viscous shearing stresses depend in a very important way on the boundary-layer thickness, and this in turn is dependent on the Reynolds' Number. In contradistinction to the conclusions drawn in the part of the paper in question, it is one of the basic consequences of the Prandtl boundary-layer theory that the separation point of a *laminar* boundary-layer is entirely independent of the Reynolds' Number and always occurs at a fixed point on the surface of a given body set at

[1] See *Journées Techniques Internationale de l'Aeronautique*, Blondel La Rougery, Paris, 1932; Quelques Problemes Actuels de l'Aerodynamique, by Theodor von Kármán.

[2] See *Aircraft Engineering*, August, 1933, London; On the Maximum Lift-Coefficient and the State of Turbulence in Wind Tunnels and the Free Atmosphere, by Clark B. Millikan and A. L. Klein.

a fixed orientation in an external flow. That this is the case can be seen very easily from the Prandtl equation. If we divide all velocities by a characteristic velocity V, and all lengths by a characteristic length L, and define the Reynolds' Number by $R = VL/d$, then the boundary-layer equation for steady motion may be written in the form:

$$u\frac{du}{dx} + v\frac{du}{dy} = -\frac{1}{R}\left(\frac{d^2u}{dy^2}\right) + U\frac{dU}{dx} \qquad (1)$$

where

x = Dimensionless distance along the wall measured from the forward stagnation point

y = Dimensionless distance measured perpendicularly from the wall

u and v = Dimensionless velocities in the boundary-layer, parallel and perpendicular, respectively, to the wall

U = Dimensionless (potential) velocity just outside the boundary-layer

In Equation (1), everything except R itself is independent of the Reynolds' Number. We can eliminate R completely by writing $v_1 = \sqrt{R} \cdot v$ and $y_1 = \sqrt{R} \cdot y$. Equation (1) then becomes:

$$u\frac{du}{dx} + v_1\frac{du}{dy_1} = \frac{d^2u}{dy_1^2} + U\frac{dU}{dx} \qquad (2)$$

The solution of Equation (2) in the form $u = u(x,y_1)$, $v_1 = v_1(x,y_1)$ is entirely independent of Reynolds' Number; that is, if the initial-boundary-layer profile at the stagnation-point origin is independent of R. But this is the case, since, at $x = 0$, we have $u = 0$ independently of the value of R. The separation criterion is:

$$\left(\frac{du}{dy}\right)_{y=0} = 0 \quad \text{or} \quad \left(\frac{du}{dy_1}\right)_{y_1=0} = 0$$

If we apply this condition to the solution $u = u(x,y_1)$, we obtain a definite value of x at which the separation point occurs, and this value of x is obviously independent of R. In other words, for the range of Reynolds' Numbers in which the laminar boundary-layer theory is valid, the separation point is independent of the Reynolds' Number. The foregoing reasoning follows that used by Tollmien[3].

Turbulence

I am not convinced that, for Reynolds' Numbers encountered in normal wind tunnels or in flight, the degree of turbulence in the wake behind the separation point has an important influence on the value of the maximum lift. The essential fact seems to be as mentioned at the end of the section "Turbulence" in Mr. Jacobs' paper, that, with increasing Reynolds' Number, turbulence may occur in the boundary layer itself upstream from the laminar separation-point. It is known that a turbulent boundary-layer resists separation much more than does a laminar one, so that this transition to the turbulent regime in the boundary layer seems to be adequate to explain the increase in maximum lift, at least up to Reynolds' Numbers of the order of 2,000,000. So far as I am aware, no theoretical considerations exist at present which furnish even a satisfactory qualitative picture for the maximum-lift phenomenon at still higher Reynolds' Numbers. However, it might be mentioned that I am at present engaged in a theoretical investigation of the fully developed turbulent boundary-layer which, it is hoped, may extend our ideas of this phenomenon to the region of arbitrarily large Reynolds' Numbers.

In conclusion, it should be pointed out that the maximum-lift curves given in the paper for the variable-density and full-scale tunnels are of exactly the same nature as similar curves obtained at *Galcit* by varying the turbulence artifically, which curves were first published[1] by Dr. von Kármán in December, 1932. The *Galcit* curves do not, of course, extend to such high Reynolds' Numbers as do the N.A.C.A. curves.

[3]See Handbuch der Experimental Physik, vol. 4, part 1, p. 251.

Airfoil Aerodynamic-Characteristic Variation

—**R. J. Woods**
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A GREAT mass of technical data has been compiled on aerodynamics. The fields of mathematics, empirical formulas, physical testing and methods of testing have been well patronized. Of the aerodynamic problems, the question of airfoil-contour selection is always the first consideration in an airplane design. From the practical viewpoint of the designer who is faced with the problem of producing a satisfactory airplane, the difference between the ideal mathematical airfoil calculations, the wind-tunnel-model airfoil-tests and actual-flight results has been very discouraging and, in the past, there have been few or no data of the nature of a measuring stick that could be used to show the way to rationalization of these apparent discrepancies. In general, rather than take the initiative and "rush in where angels fear to tread", designers have carried on by the use of a certain few airfoil sections known from actual-flight experience to be acceptable.

The field for selection of airfoils in this manner was continually reduced until, quite recently, only two or three basic airfoils were being generally used in this country. However, the demand for aircraft with increased speed-ranges and the requirements for modern military aircraft to dive at terminal velocity propagated a situation where the old standard airfoils no longer sufficed.

Mr. Jacobs has carefully pointed out in the first part of his paper why a mathematical calculation will not provide the easy solution for airfoil selection; namely, that the factors which provide the variable characteristics from which the selection of an airfoil is made do not appear in the theoretical calculations. Since this is the case, physical tests must then be used for the determination of airfoil characteristics for comparison for the purpose of selection. The method used by the N.A.C.A. and presented by Mr. Jacobs for the preparation and design of a systematic family of airfoils, in the latter part of his paper, is certainly very rational and practical. The method of identification used for this family of airfoil sections is especially ingenious. The completed test-data of such a family of airfoils will be most valuable to a designer for airfoil selection. It is without doubt the most complete and logical work of this kind so far compiled.

However, when the airfoil has been selected by comparison of characteristics, the designer's problems are not all solved. The constantly increasing speed-ranges of modern aircraft and the prolific development of structural requirements and design conditions place the designer in a position

where he must not only have the most suitable airfoil, but must know, within practical limits, the aerodynamic characteristics of the airfoil chosen over a wide range of Reynolds'-Number values. Mr. Jacobs has pointed out and explained very carefully the manner in which the fluid friction or viscosity of the air affects aerodynamic characteristics of airfoils. The process of showing why physical tests of model airfoils are necessary will explain clearly why, if these tests of model airfoils are to be of practical use for the detail design and stress analysis of aircraft, some additional data must be furnished for interpolation of the test results as given in the general airfoil-test report. These data should be such that a correction can be made in the value of the coefficients of the characteristics shown in the standard airfoil test to correct to a Reynolds'-Number value rational to the specific design condition of the particular airplane under consideration.

It is obvious that, for an airplane with a stalling speed of 60 m.p.h., a maximum horizontal speed of 250 m.p.h. and a terminal velocity of 500 m.p.h., and such aircraft are actually being built, that airfoil characteristics at one Reynolds'-Number value will not be sufficiently accurate where the design conditions cover such extended speed ranges, since the change in Reynolds'-Number is shown to be directly proportional to the change in velocity, other things being equal.

The N.A.C.A. and Mr. Jacobs are to be congratulated upon the excellent work thus far done on this problem of providing a logical and practical basis for the selection of airfoils. Mr. Jacobs' paper covers very well the explanation of the fluid mechanics acting to produce the variable characteristics that occur when airfoils are physically tested; however, the job is not yet done. It seems that if the full practical value of this thorough investigation of a related family of airfoils is to be realized by the designer, some additional information must be furnished whereby the qualitative data of the model-test reports can be changed to quantitative data applicable directly to the design and stress analysis of aircraft.

Simpler Treatment Advocated for Empirical Profile-Drag Data

—**Ralph H. Upson**
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ONE of the few things about Mr. Jacobs' fine paper that might be improved seems to be his empirical treatment of profile drag. The great value of an empirical equation, for an experimental set of points, is to permit mathematical study and handling of combinations and conditions related to, but not specifically represented in, the experimental data themselves. This simplicity, completeness and direct approach to practical design-conditions, are much to be desired.

Starting with the formula for minimum profile-drag of symmetrical sections, instead of the three-term equation submitted in the paper we can substitute the two-term equation

$$C_{Do\,min.} = 0.0065 + 0.125t^2 \qquad (1)$$

which fits the experimental points almost perfectly except for a slight discrepancy in the lowest one, and agrees better with the generally accepted coefficient for $t = 0$, assuming equivalent scale and flow effects.

For other than symmetrical sections, the minimum profile-drag and the corresponding lift-coefficient—termed optimum lift-coefficient in the paper—are characteristics easily obtained from the wind-tunnel results; but, unfortunately, they are of no direct interest to the airplane designer.

Profile drag is of importance only in relation to the structural and operating conditions with which it is associated. Thickness is the main criterion of the former, and lift coefficient of the latter. The problem is not to find the lowest profile drag and the lift coefficient at which it occurs, but to determine the best all-round compromise between thickness and drag for the required range of lift coefficient. Based on Mr. Jacobs' results, the general relation between these three important parameters can be expressed by the simple equation[4]:

$$C_{Do} = (0.0065 + 0.125t^2)\,(1 + 0.7C_L^3) \qquad (2)$$

where C_{Do} in this case is not the minimum for a given airfoil but the minimum for a whole family of cambered airfoils of a given thickness and at a given lift-coefficient. When these three fundamentals are established, of course in relation to induced drag and the other essential elements, the engineer can then profitably consider the detail airfoil-characteristics, including maximum lift, for which no empirical equations are necessary or desirable.

The foregoing Equation (2) gives a good practical approximation for the entire range of thickness and curvature and for lifts up to near the burble point in most cases. The slight departures from experiment are probably in the direction of a closer approach to free-air conditions, though further experiments here and in the full-scale tunnel would be necessary for real accuracy.

[4] See S.A.E. JOURNAL, January, 1930, p. 15; Wings—a Coordinated System of Basic Design, by Ralph H. Upson. [Equation (2), herewith, corresponds to the one established by Mr. Upson in the paper referred to, but with coefficients corrected to conform with the large mass of experimental data now made available.]

Procedure for Choosing An Airplane Airfoil

—**Shatswell Ober**
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THE paper gives a most welcome relief from the intricate, often useless, "criteria" of airfoil selection generally found in a treatment of this subject. In choosing an airfoil for an airplane the simplest procedure is to allow the structural requirements to fix the thickness, using the thinnest airfoil consistent with economical spar depths; then, since the minimum speed is dictated either by rules or by common sense, the lowest wing-profile drag will result by using the section giving the maximum ratio of $C_{Lmax.}/C_{Dmin.}$ provided the wing weight is not affected by small changes in area. From the data in the paper, sections of Series 23 or 24 appear best. In practice, it probably would be found that the wing weight would be more nearly constant per square foot; if so, airfoils of Series 43 or 44 would be preferable because of their higher values of $C_{Lmax.}$. The thickness would increase with wing loading (landing speed), load factors, and reduction of external bracing, but there is little reason why airfoils on all types of plane should not be otherwise similar.

It is to be regretted that the author did not include any data on sections with reflexed trailing edges, otherwise similar to the 24 or 44 Series. Such sections tend toward avoiding excessive loads in a dive, and excessive changes in trimming speed power on and off. I understand such sections have been tested.